AN ABSTRACT OF THE THESIS OF

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Title: Feasibility Study for a Tillamook County Dairy Waste Treatment and Methane Generation Facility

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With the expansion of the Tillamook Creamery, in Tillamook Oregon, to double or more its cheese production, the demand for milk presents an economic opportunity for the member dairies of the Tillamook County Creamery Association. Before area dairies can expand their herd size to increase milk production for the creamery, the problem of manure waste management and pollution control must be solved. This study considers the technical and economic feasibility of developing a centralized waste treatment and methane generation facility to treat manure generated by Tillamook County dairies. A computer program modeling animal waste anaerobic digester design served as the basis for generating cost and production estimates for several hypothetical scenarios assuming input data specific to the Tillamook situation. A

follow up study was also made to determine the variability of the potential ultimate methane yield of manures from Tillamook dairies.

This study indicates that the proposed system is technically feasible. The study estimates that a comprehensive treatment system could cost dairymen from $70 to $100 per cow per year to start, but the economic feasibility improves as more manure is treated and more dairies participate. A full scale system has the potential to break even economically from the sale of electricity produced by a 5 megawatt methane powered generator. With the marketing of treated solids as a high grade fertilizer the system could gross a return of $1 to $75 per cow per year, depending on the scenario.

Feasibility Study for a Tillamook County Dairy Waste Treatment and Methane Generation Facility

by

Thom G. Edgar

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PREFACE

This thesis is comprised of two manuscripts. The bulk of the work consists of a "Feasibility Study for a Tillamook County Dairy Waste Treatment and Methane Generation Facility", which was completed and presented to the Tillamook Methane Energy and Agricultural Development Committee in February, 1991. The second manuscript, "A Comparison of Tillamook Dairy Manures for Ultimate Methane Yield" presents the results of a follow up laboratory experiment run during the summer of 1991. It was undertaken to provide data to Universal Synergetics Inc., Seattle, Washington, the company retained by the Tillamook committee to proceed with the development of a centralized dairy waste treatment facility.

Feasibility Study for a Tillamook County Dairy Waste Treatment and Methane Generation Facility

INTRODUCTION

Purpose

This report has been assembled in fulfillment of Task A.1 of a core feasibility study for the Tillamook Methane Energy and Agricultural Development (MEAD) Policy Committee. The objective of this report is to evaluate the feasibility of using anaerobic digestion to treat dairy manure wastes as an alternative method of addressing Tillamook County's perceived and potential dairy waste management problems.

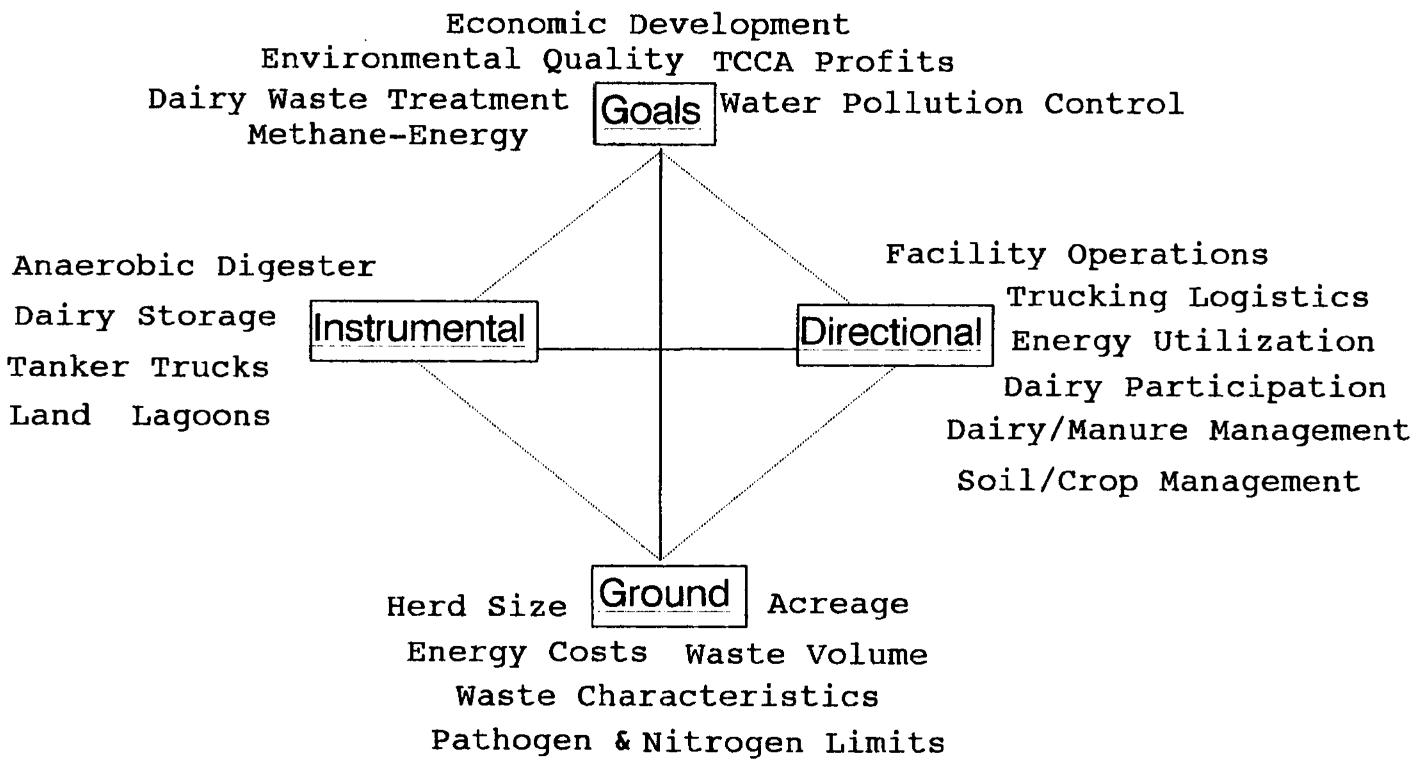
With the expansion of the Tillamook Creamery's capacity to double (or more) its cheese production, the opportunity exists for the members of the Tillamook County Creamery Association (TCCA) to increase the county's milk production. However, before the 191 area dairies can increase their current dairy herd size of nearly 26,000 cows (1400 lb cow-units), the problem of manure waste management must be solved. With the current cow population already producing a potential 177 metric tons daily (195 tons U.S.) of total manure solids there exists a history of water quality problems in the county watersheds. There is a concern about pathogens, attributable to livestock and other sources. Intermittent elevated coliform counts in the oyster harvesting areas of Tillamook Bay have resulted in fishing closures of the bay and fines to the TCCA. The fate of nitrogen is also a major concern as a potential threat to public health. This nutrient in the form of nitrates can pollute both surface and groundwater. Estimates indicate that the nitrogen loading rate to the agricultural pasture lands of the county is approaching agronomic limits. The region's poor draining soil, high rainfall, and high water-table pose environmental limits on agricultural practices that cannot be improved easily by conventional methods. Any plan to significantly increase animal numbers must include alternatives of managing manure. Waste management alternatives must responsibly account for the pathogens and nitrogen in excess of the crop uptake rate. This report assesses the economic and technical feasibility for constructing a centralized dairy-waste treatment system with which to collectively treat and stabilize the county's dairy manure.

Approach

This study is based largely upon information provided by the Tillamook County Creamery Association and the Tillamook Soil Conservation Service regarding the region's dairy industry. The analysis of this information was accomplished primarily using a computer program which models animal-waste anaerobic digestion system design (Hashimoto, et *al*, 1986), providing quantitative estimates of a hypothetical system's performance and costs. Numerical values are calculated according to accepted engineering design principles and formulae (it must be emphasized the values presented in this study are academic estimates, and are not to be mistaken to be as accurate as a commercial engineering firm's projections and bid for a specific system design).

In order to allow for a comprehensive assessment of all the factors to be considered in reaching the conclusions of this study, this report addresses the issues in four main sections. An overview of this project requires understanding four distinct facets of the activity being undertaken

Figure 1 - Project Overview



Overview of M.E.A.D. Project Factors

(fig. 1). These facets can be described by the 'ground state' or current status of resources; the 'goal' or solution to be achieved; the 'instrumental' materials, equipment, and processes to accomplish the goal; and the 'directional' management decisions to effectively undertake the activity. With this overview of the project in mind, this report is divided into the following sections:

Section 1. "Facts of Tillamook County Dairy Industry"; This section discusses the 'ground state' of the project and the fundamental data used to indicate the scope of the problem, including the numbers of cows and dairies, acreage and manure pollution problems.

Section 2. "Waste Treatment Facility Description"; This section presents the 'instrumental' facets of the project. A general description of the anaerobic digester system modeled by the computer program. Discussion of the technical feasibility of pathogen reduction and nitrogen control options.

Section 3. "Trucking Cost Estimates"; This section addresses major 'directional' aspects, logistical and operational, of the project. Several key assumptions are discussed which lead to evaluating different possible project scenarios.

Section 4. "Economic Feasibility"; The 'goal' of evaluating whether the project is feasible. Further key decision/assumptions are discussed in evaluating the possible scenarios and their respective 'bottom line' values.

There are many variables involved in the task of finally arriving at some 'bottom line' figures evaluating the economic feasibility of the proposed large-scale activity. There are innumerable combinations involving multiple assumptions; the number of cows and extent of dairies to be participating, volume and characteristics of the waste, material and energy costs, thermodynamic and bio-kinetic efficiencies, etc. In order to simplify to some extent the number of scenarios evaluated in this report, this discussion is limited to 'best case', 'worst case', and 'most likely case' scenarios. These three type cases are considered with respect to the Tillamook County dairies being located in three focal areas, i.e. the Port of Tillamook as 'central county', the town of Cloverdale as 'south county', and the town of Nehalem as 'north county'. More complete definitions of best, worst, and most likely case scenarios will be made in the section "Trucking Cost Estimates".

TILLAMOOK COUNTY DAIRY INDUSTRY

In this section some of the basic facts affecting the goal of waste treatment in Tillamook County are presented. The sources and methods of arriving at these 'facts', which are generally 'best guesses', are discussed.

Herd Size

The key factor for sizing a proposed digester and evaluating its energy production and economic potential is determining just how much waste the plant will be expected to process. The quantity of waste can be determined by estimating how much waste will be generated by the number of cows from the number of dairies the digester can be expected to service. Unfortunately there is no current census report on the Tillamook County cow population. Furthermore, cow numbers are not held constant because dairymen adjust herd sizes from season to season as market conditions warrant. For this report a best guess approximation of the county cow population was made by utilizing data on file from the Tillamook County Creamery Association (TCCA) and the Tillamook County Soil Conservation Service (SCS) data. Cow numbers from the TCCA represented a head count of milkers in production. Numbers obtained from the SCS represented all cows at the site, i.e. milkers, heifers, etc., and the head count was normalized to values of cow-units by weight, either 1400 lb (SCS) or 1000 lb (TCCA) units. A dairy by dairy correlation was made between SCS and TCCA cow numbers and an average ratio computed of SCS/TCCA. This ratio is estimated to be 1.20 1400 lb cow-units per head of milker cows. For dairies which had both SCS and TCCA cow numbers this report uses the SCS value, as that data is more current than TCCA data. For dairies with no SCS values, the TCCA value was multiplied by the ratio calculated above. The product used in the summation for the total county cow population estimates is in terms of 1400 lb equivalent units.

Mileage

The distance from each participating dairy to the treatment plant needs to be known in order to make an accurate estimate of the trucking costs involved in hauling manure to the centralized plant(s). Distances were determined by locating county dairy locations on a 1 mile to the inch road map of Tillamook County. Distances from each farm located on the map were measured to a location sited at the Port of Tillamook airport. Mileages were similarly measured for the alternative of there being local sites at Cloverdale and Nehalem, as well as the central Tillamook location. Dairy locations were determined from addresses and maps on file from the TCCA and the SCS.

Acreage

Total agricultural land and other acreage available to the TCCA were estimated to determine the possible alternatives for ultimate disposal of the treated sludge. The nutrient capacity of the county's crop and pasture lands is a critical factor in the event the county cow population is doubled. Figures arrived at for this study indicate that there are 23,540 acres of pasture and cropland among the central Tillamook dairy farms, and approximately 11,500 additional acres of agricultural land in the rest of the county, for a total of 35,000 acres of farmland (Dept. of Community Development, 1990).

Manure & Water Quality

The entire impetus for this project stems from the concern that Tillamook County has a water pollution problem due to the concentration of dairy wastes. This section presents some of the assumptions regarding targeted standards for water quality and recommended manure application rates. The most apparent problem has been with pathogen concentrations exceeding DEQ standards for fecal coliform levels in Tillamook Bay. Excess pathogen counts force bay closures affecting Oregon's primary oyster growing area, as well as recreational clam digging, fishing, and boating. With raw waste fecal coliform counts on the order of 106 FC/100 ml, runoff of animal wastes into the county's streams must be controlled to prevent bacterial contamination. The stream bacteria standard is 200 FC/100 ml and the bay standard is 14 FC/100 ml. Even after dilution from rainwaters, fecal coliform counts from 1000 FC/100 ml to over 6000 FC/100 ml have been monitored during the fall months in Tillamook area waterways (TBRCWP, 1984). Progress has been made in recent years with improving manure management in area dairies, but the fecal coliform problem is not yet fully solved. The prospect of increasing the area's cow population also presents the problem of nitrogen control. Although there is no evidence that nitrate levels in area wells and surface waters are currently posing a public health risk, there is a general consensus among interested agencies that the number of cows per acre for many Tillamook area dairies is at or above the recommended rate. The suggested recommended nutrient application rate on pasture land on the Oregon coast for nitrogen is 220 lb/acre per year (Moore,J.A., Gamroth,M.J.,1989). Assuming 0.57 lb N/1400 lb-cow per day (Midwest Plan Service, 1989), a single cow can generate 208 pounds of nitrogen per year. By these numbers, there needs to be 0.95 acres available per 1400 lb unit-cow for the application of manure onto dairyland. Table 1 presents the basic dairy cow waste characteristics assumed for this study.

Summary of Tillamook Dairy Numbers

A total of 210 potential dairy locations were tabulated by the correlation of TCCA and SCS data. Of these, 191 dairies were located on the map. It is presumed that most of the remaining 19 farm names unaccounted for are duplicate entries caused by unrecorded changes of ownership and management. Of the 191 located producers, 118 were located around the central county in or near Tillamook, within a range 10.5 miles to the Port of Tillamook site. There are 58 producers found located in the south county between Cloverdale and Tillamook, ranging from 10.5 to 26 miles away from the port site. There are 14 producers found for the north county near Nehalem, ranging from 28 to 33 miles from the port site (fig. 2). Using SCS file numbers only, it is estimated that there are 23,296 1400 lb equivalent cow-units county wide. By TCCA numbers only, the estimate is 21,708 1000 lb equivalent units. Correlating SCS and TCCA data yields an estimated 25,996 cow-units for the 191 farms located. The 19 unaccounted for producers have an estimated 2,626 cow-units. Therefore, the county cow population for the 210 producer names tabulated is potentially 28,620 1400 lb cow-units. Until the unlocated producers are accounted for as well as until all cow numbers are verified and updated, the value of 25,996 1400 lb cow-units for the 191 located farms is assumed for the county cow population. This amounts to 64.4% of the total county herd size located within 10.5 miles of the Port of Tillamook, 27.9% within 10 miles of Cloverdale, and 7.7% of the cow population within 5 miles of Nehalem (fig. 3).

Table 1 - Dairy Cow Waste Characteristics

Parameter	Values per Milk Cow
Average weight per equivalent milk cow	1400 lb.
Total waste (volume)(including washwater and allowed precipitation)	26 gal/day
Total waste (mass)	217 lb/day
COD (chemical Oxygen Demand)	11.37 lb/day
TKN (Total Kjeldahl Nitrogen)	0.57 lb/day
K (Potassium)	0.33 lb/day
TVS (Total Volatile Solids)	12 lb/day
TSS (Total Suspended Solids)	15 lb/day

Figure 2 - Cow Population Distribution
Tillamook County, 1989

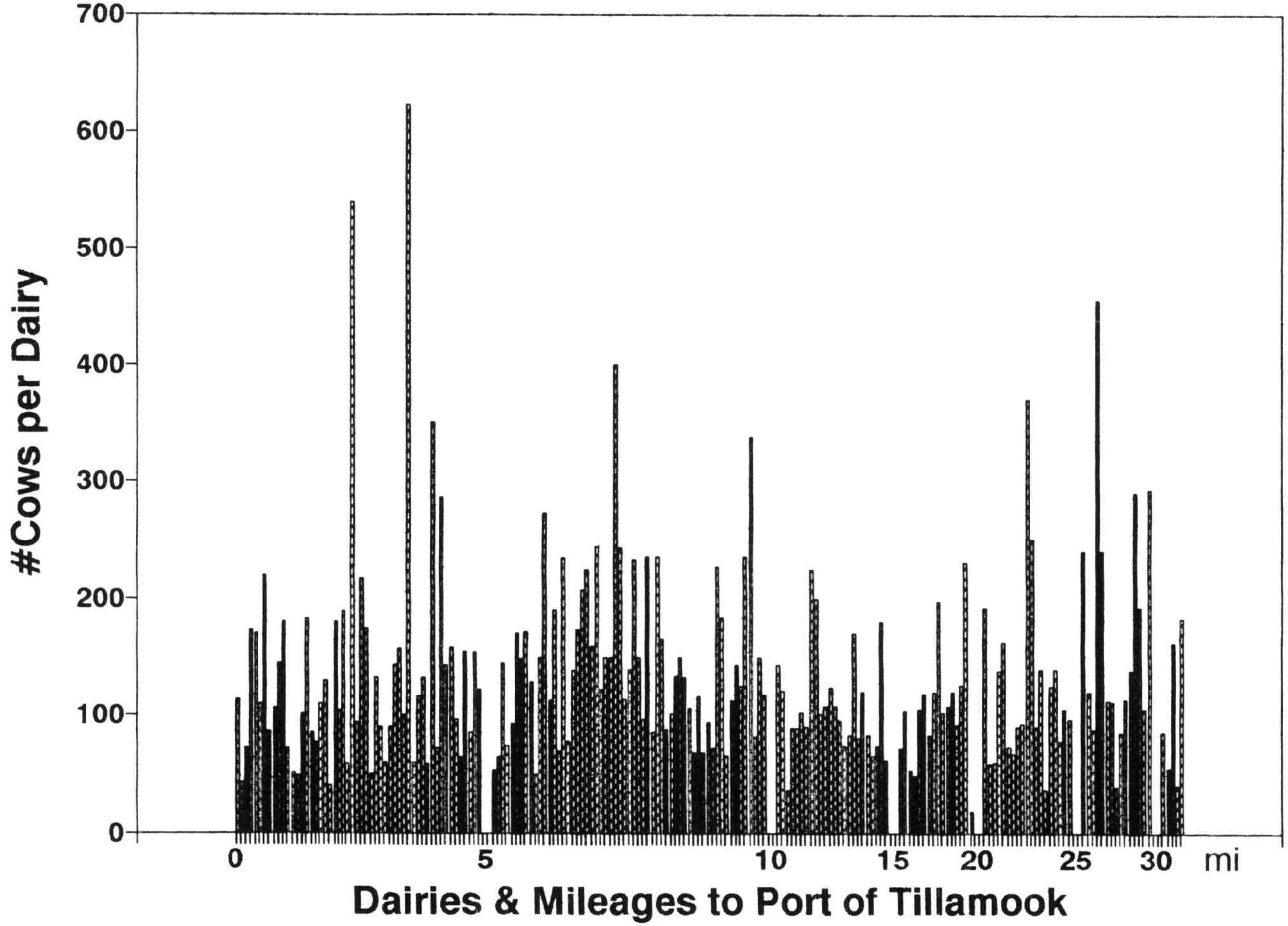
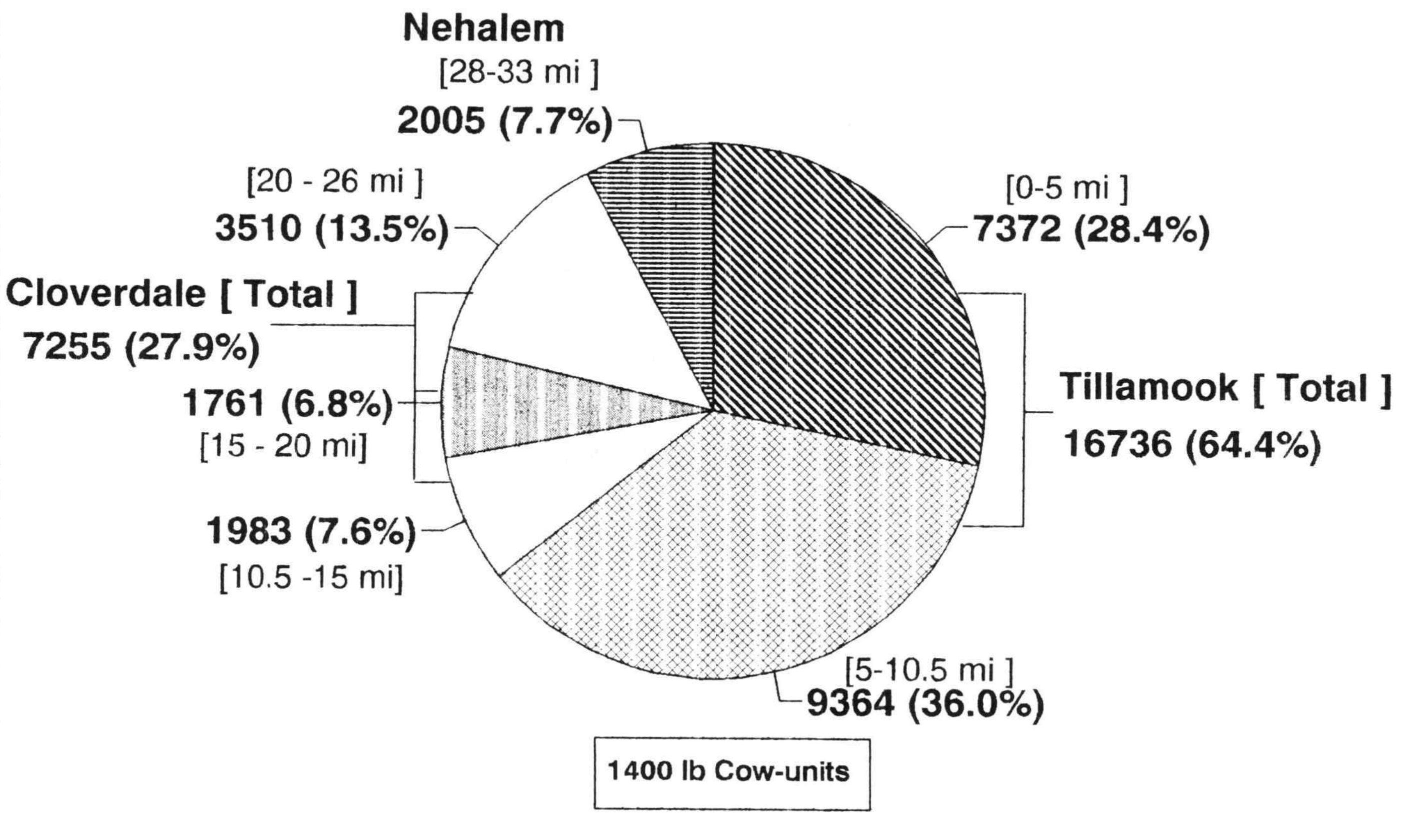


Figure 3 -County Herd Size
Tillamook County, 1989



WASTE TREATMENT FACILITY DESCRIPTION

The economic feasibility of a waste treatment facility can be realistically evaluated only after determining its technical feasibility for solving the dairy waste management problems of the county. This section addresses the issues regarding:

- the process of anaerobic digestion, producing methane gas as a commercial energy source;
- the effectiveness of anaerobic digestion in the reduction of pathogens in waste sludge;
- nitrogen reduction methods and treatment efficiencies of possible technological options;
- the ultimate disposal of the treated effluent and sludge.

Anaerobic Digester System

The technology of anaerobic digestion of organic wastes has been studied extensively since the 1920's and is a process commonly used by municipal sewage treatment plants today. A resurgence of scientific and engineering interests in methane production occurred with the 'energy crunch' of 1973 and subsequent progress been made in fundamental understanding and control of the process (Metcalf,Eddy, 1979). The utilization of the process for the treatment of livestock wastes, although not as widespread as it is for municipal wastes, is being successfully applied at Midwest beef feedlots, swine operations, and poultry operations, as well as dairy farms. Anaerobic digestion is a biological process, occurring in the absence of air, by which the organic solids of a waste are degraded and partially consumed by a consortium of anaerobic bacteria. The bacteria metabolize organic nutrients available in the waste slurry and perform most efficiently in a heated environment (90° - 160° F). The resultant products of the process are methane gas (CH_4), carbon dioxide (CO_2) and trace amounts of other gases, bacterial mass, and sludge (the residual waste solids reduced by the partial digestion of volatile solids).

The advantages of the process are:

- it is odorless, occurring in airtight tanks;
- the organic content is reduced, diminishing BOD strength of the effluent;
- most weed seeds and pathogens are killed;
- rodents and flies are not attracted to the resultant sludge;
- fertilizer constituents of the waste are conserved;
- a combustible gas is generated that is valuable for energy production.

There are two main disadvantages of anaerobic digestion systems:

- they are sensitive, biologically, to environmental changes and so require diligent management to maintain stable digester conditions;
- the digested sludge remains potentially a pollutant hazard if not carefully managed.

More specifically to the concerns in Tillamook, the total nitrogen concentration of the influent is not reduced by anaerobic digestion.

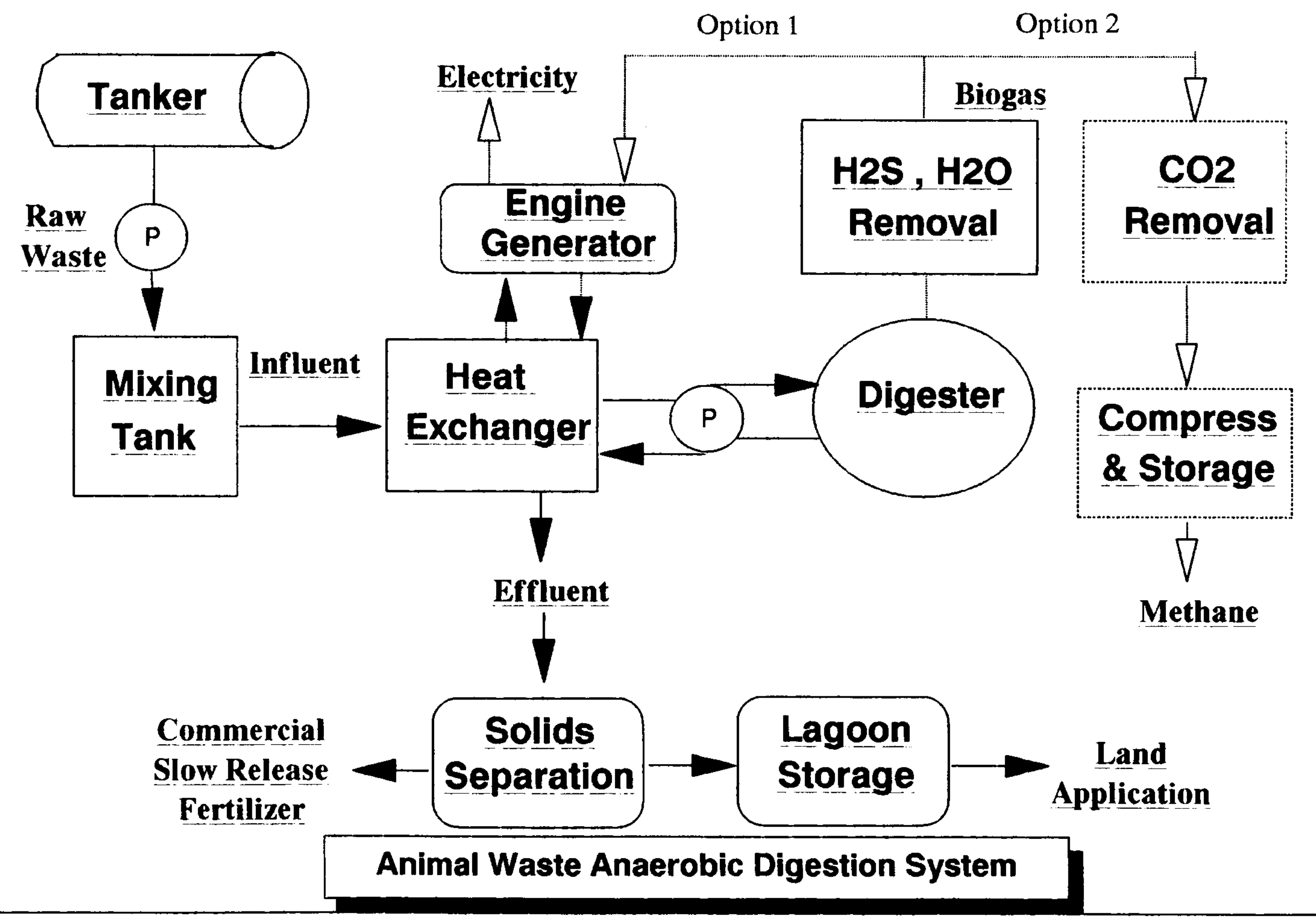
<u>System Description:</u> There are several types of anaerobic digestion system designs, differing in both operational and structural details. The system modeled for the purposes of this study is a conventional, high-rate, one-pass system. This section provides a general description of the flow scheme and components which comprise the system. Dairy waste from participating farms is delivered as a slurry to the plant site by tanker trucks. The slurry is unloaded from the

tankers into a mixing-holding tank, where dilution water is added if necessary. From the holding tank the slurry is pumped through a heat exchanger to the digester. The digester is thermally insulated and equipped with a mechanical mixer and heat exchanger for temperature control. Effluent from the digester passes through the heat exchanger to partially heat the influent (figure 4).

Biogas generated under the anaerobic conditions of the digester is continuously siphoned off, scrubbed to remove hydrogen sulfide and moisture, and used directly as fuel for an internal combustion engine/generator to produce electricity. The liquid radiator/cooling system of the generator acts as the thermal energy source for the slurry heat exchanger. There is also the option to further scrub the biogas of CO_2, yielding a virtually pure methane fuel that is compressed and stored for portable use (e.g. natural gas powered vehicles, substitute fuel for rural propane and natural gas appliances). Each digester is designed to have a maximum liquid height of 10 meters (32.8 ft) and a maximum diameter of 80 meters (262.5 ft) for a maximum volume of 5027 cubic meters (6575 cubic yards). Each digester will cover a maximum area of 0.50 hectares (1.24 acres). The normal working volume is 85% of the total digester volume allowing head space for partial gas storage and for daily fluctuations in influent delivery. Systems requiring volumes greater than 5027 cubic meters are designed with multiple, equal-volume digesters.

The system is conventional, as it is similar to municipal anaerobic digestion units. The sludge is not recycled through the digester, as in aerobic activated sludge treatment, hence it is a one-pass system. It is a high-rate system due to maintaining an elevated slurry temperature, and

Figure 4 - Flow Scheme



by periodic mixing of the slurry to prevent stratification of substrate solids and to promote a high level of bacterial activity throughout the digester.

System Design Approach: The "Animal-Waste Anaerobic Digester System Design" computer program requires more than sixty variable inputs in order to calculate and determine a comparable number of output parameters which describe the system. The general areas of concern in designing the system are:

- physical plant size; depending on the daily total waste volume to be treated and the duration of treatment, i.e. the hydraulic retention time.
- thermal energy requirements; based on principles of heat transfer and thermodynamics to model the system's overall energy balance.
- gas production; based on mathematical models of fermentation kinetics regarding anaerobic microbiology, waste characteristics and system operating temperature.
- electrical production; depending on gas production and the assumed mechanical efficiency of the generator.
- construction costs; depending on the total digester volume and gas use options.
- operational costs; depending on estimated values for annual trucking costs, labor, maintenance, cost of capital, and value of electrical energy sold.

Although there are many variables involved in the program design of the anaerobic digester system, the majority of variables used in calculating the mechanical performance of the system are default values typical of a generic digester system. A further description of the above mentioned areas and a brief discussion of assumptions made about some design variables specific to Tillamook follow.

Physical Plant Size: The daily total waste volume is the fundamental unknown variable affecting the economic feasibility of this project. An assessment of the possible scenarios due to assuming various daily total manure solids to be processed by the plant begins in the section "Trucking Cost Estimates". A critical factor is the total solids concentration of the raw waste and the digester's design slurry concentration. The default value of the slurry total solids (TS) concentration is assumed to be 10%, however if the raw waste is assumed to be less than 10% TS, then the digester TS concentration is assumed to be that of the raw waste. The difference between designing for a 10% or 7% digester slurry concentration translates to several hundred thousand dollars difference in construction costs due to the larger digester volume required for the more dilute influent. The hydraulic retention time (HRT) also significantly determines the plant size. The HRT is the number of days the system is designed to retain the daily influent volume for digestion. Hence the longer the design HRT, the larger the digester volume and overall plant size. Typical HRT's range from ten to thirty days, with the longer retention times yielding higher gas production per mass of solids fed, as well as greater reduction in volatile solids. For this study, a default design HRT of 12 days was assumed as a constant in all the scenarios. (Preliminary comparisons made while assembling this study indicated a 12 day HRT, at thermophilic temperatures, to be a reasonable assumption for optimizing gas production while minimizing construction costs.)

Thermal Energy Requirements: An energy balance of the system needs to be calculated in order to determine the net energy production and quality of energy available after all system requirements are met. Heating requirements, pumping and mixing power requirements, generator and heat exchanger efficiencies are all significant factors in determining the system's performance. The key variable in estimating the energy requirements for the system is the design operating temperature of the digester. There are two classes of methanogenic bacteria, based on temperature, for which a system can be designed. 'Mesophilic' bacteria thrive in a temperature range from 90° to 105° F, and 'thermophilic' bacteria are most active in a range from 120° to 150°F. Although system energy requirements are, of course, higher when the digester is maintained at thermophilic temperatures, a higher rate of gas production allows for shorter hydraulic retention times, and in turn a smaller digester volume. For this study, the assumption was made that the design operating temperature of the digester is 55° C (130° F).

Gas Production: The prospect of attaining an economic return from the operation of an anaerobic digester depends on the quantity of useful energy it can produce in the form of methane gas. The projections drawn in this study are based on some mathematical models which simplify into a few terms what is in fact a complicated biological process. Besides the system parameters already outlined, there are several more variables required regarding waste characteristics and bacterial activity. The primary variable that needs to be known is the ultimate methane yield, measured in terms of volume of methane produced per mass of volatile solids in the manure (m^3-CH_4/kg-VS). This factor is strongly influenced by the nature of the feed the animals eat. Typical ultimate methane yield values for dairy cattle have been reported to range from 0.20 to 0.40 m^3 CH_4/kg. Preliminary lab tests undertaken at OSU on a small random sample of Tillamook dairy manures have indicated a range of from 0.24 to 0.30 m^3 CH_4/kg (Sibidie,A., 1990). The default value assumed for this study is 0.28 m^3 CH_4/kg-VS.

Electrical Production: There is no infrastructure to distribute or use natural gas (methane) in the Tillamook area. Therefore, generating electrical power by using the methane in an internal combustion engine/generator is assumed. Electrical energy production is calculated by the theoretical energy content of digester gas produced and the conversion efficiency of the generator. The generator efficiency is a function of its size, with a best possible efficiency of about 35% conversion of the gas thermal energy content to electrical energy.

Construction Costs: The construction costs are a function of the total volume of the digester and the gas use options employed in the design. The costs are based upon references to known cost and size of similarly designed systems and adjusted by a scaling factor to allow for economy of scale (Hashimoto,Chen, 1981). Reference costs used by the original anaerobic digester design program are adjusted for inflation (Engineering News Record, Construction Cost Index; index ratio for 1990/1985 = 1.118). The basic reference cost assumed for the system design used in this report is $69,300 for a 100 m^3 (3530 ft^3) digester with the biogas used directly for a generator.

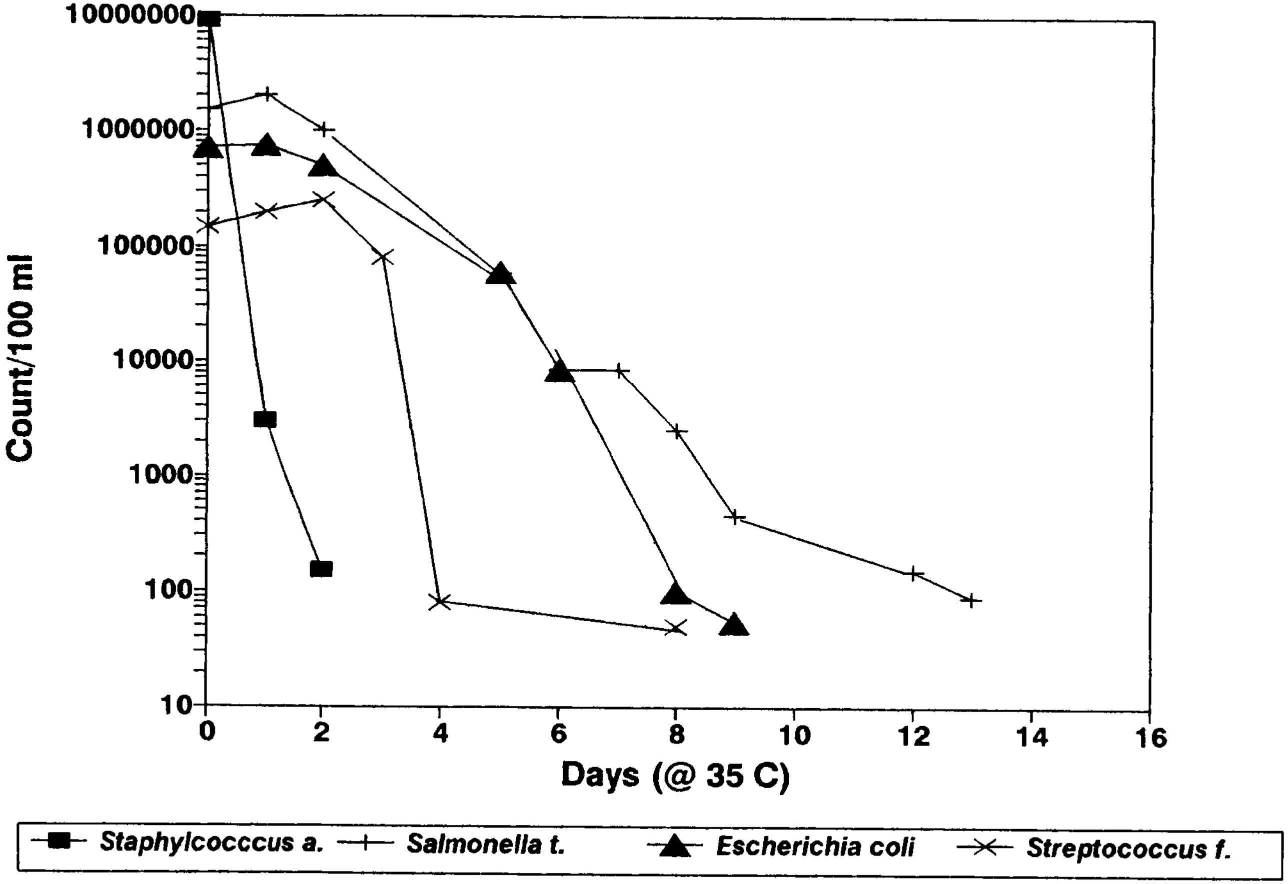
Operational Costs: The annual operational cost of the system is calculated by the summation of the labor, maintenance and utility (i.e. water), annual debt repayment, and trucking operation costs, minus the value of the electrical energy sold to the Tillamook People's Utility District. Similarly to construction cost, labor costs are calculated based on digester volume, and are estimated to be $8,453 per year for a 100 m^3 digester. A more thorough discussion of construction and operational costs is presented in the section "Scenario Results".

Pathogen Reduction

One of the goals of this project is the reduction of pathogens introduced into Tillamook County water due to the dairy wastes. The technical feasibility of accomplishing this goal is possible with an anaerobic digester. The animal waste anaerobic digester design program does not model the effect of system parameters on pathogens, however a literature review of the subject indicates that pathogen concentrations are substantially reduced by anaerobic digestion.

Studies have been published concerning pathogen and pathogenic indicator organisms, including *escherichia coli*, *streptococcus faecalis*, *salmonella typhimurium*, and coliform bacteria. These studies show that a 90% reduction of organism concentration can occur in one to five days under thermophilic and mesophilic anaerobic conditions, respectively, with faster decimation rates occurring at higher temperatures (Olsen, *et. al.*, 1986). For example, one study (Olsen,J.E., 1987) on cattle slurry indicates that *escherichia coli* was reduced from an initial count of 10^6 FC/100 ml to 10^5 FC/100 ml in three days and was down to 100 FC/100 ml after eight days of anaerobic digestion (figure 5). In view of the fact that the full scale digester proposed for this project will be operating at a high temperature and an HRT three to six times longer than the decimation times reported, it can be assumed with confidence that pathogen control can be fully met by anaerobic digestion.

Figure 5 - Bacteria Survival Curves
Anaerobic Digestion of Cattle Slurry



Nitrogen Reduction

Although the nitrogen content and composition of anaerobically digested animal wastes make for a valuable fertilizer, the unique environmental constraints of Tillamook necessitate reducing the effluent nitrogen prior to ultimate disposal, most probably by secondary treatment methods. As already stated, the total nitrogen content of the digester effluent is not significantly lower than the influent. However, changes do occur in the composition of nitrogen constituents in the waste. A small fraction of organic nitrogen is metabolized into bacterial mass, but the most significant change is in ammonia concentrations. Typically, about 30% of the influent total nitrogen is in ammonia (NH3-N) form. After digestion, the ammonia concentration increases to around 50% to 75% NH3-N in the effluent. About 15% NH3-N is in the sludge solids. The most readily removable fraction of total nitrogen in the effluent is ammonia. Feasible technological options to accomplish nitrogen reduction include the following.

Land Treatment: The simplest method of 'treatment' is by the application of the wastes back onto the county's pastures and crop land. The application of effluent is most commonly accomplished by sprinkler irrigation systems, but can also be accomplished by mobile spray-rig vehicles. A measured redistribution of the digester effluent to area farms could balance the nitrogen uptake rates of crops to the nutrient characteristics of the effluent. The critical factors in this method would be the problem of adequate effluent storage at both the digester site and participating farms to meet a periodic application schedule as the weather permits; the extra logistical problems of backhauling wastes around the county; an appropriate application system at each site; and having enough available land. (Land treatment options are further considered in the section "Ultimate Disposal")

Stabilization Lagoons: The next simplest method for removing nitrogen is achieved by the volatilization of ammonia into the air. Removal efficiencies of more than 90% NH_3 can be achieved by various lagoon systems. The type of system to utilize depends upon arriving at the best combination of system performance and economy. Volatilization can occur naturally in ponds without any mechanical energy requirements, but require low loading rates, on the order of 100 lb-VS/acre per day or less, and are effectively inoperative under winter conditions. The low loading rates and shallow depths required of low-rate aerobic ponds demand large pond surface areas and the corresponding land area for situating the ponds. Aerated lagoons can more rapidly strip ammonia from wastewater by using mechanical aerators and agitators, thereby exposing more surface area of the wastewater to the atmosphere and allow for higher loading rates to the lagoon. A trade-off between savings in lagoon area and retention times and the extra operational costs incurred for aerator power have to be considered in determining the feasibility of such high-rate aerobic lagoons. Detention times required of stabilization ponds can range from 4 to 7 days for energy intensive, high rate ponds, and from 200 days to a year for more passive holding ponds in order to attain high reduction levels. All lagoon treatment systems pose a potential odor problem, from environmental fluctuations and mistakes in operation. This fact needs to be taken into account in locating a lagoon site away from residential and tourist areas.

Biological Reactors: Nitrification can be achieved by utilizing bacteria in suspended growth and attached growth waste treatment processes. These processes are similar to municipal sewage treatment plants in technical complexity, only the design emphasis is in the reduction of nitrogen rather than biochemical oxygen demand. There is little practical experience with these systems for the treatment of animal manure. The technical feasibility exists to obtain high removal efficiencies with biological reactors, but the solids concentrations must be less than 2% to prevent overloading and clogging.

Ultimate Disposal

The ultimate fate of waste treatment facility effluent will be by land application for growing crops. The total amount of solids and liquids to be handled, and the nutrient composition of the waste will all depend on which nitrogen control option is chosen. The total amount of effluent solids will be about 30% less than the total solids of raw waste due to the mass conversion to biogas by anaerobic digestion. Depending on the commercial potential of the solids as a fertilizer, effluent solids may be separated and dried and shipped entirely out of the county, or in part returned to county land, or entirely returned to county land. There are two possible alternatives to consider for the destination of the liquid portion of the effluent. Both options are land treatment methods for nitrogen management; either by returning the effluent to participating farms in the county or by applying the effluent to regional forest lands.

Farm Land Application: Assuming that 0.95 acres of crop or pastureland is required per 1400 lb cow-unit for the application of nitrogen generated annually, and given the approximately

35,000 acres of agricultural land within the county, there appears to be room for expansion of the county herd size to 36,000 cow-units before nitrogen reduction becomes a real necessity. This evaluation presumes, of course, an even and measured distribution of manure over all the county farm land. In actuality this option would require dairymen and farmers with 'excess' acreage to accept wastes from dairies with 'excess' cows. It also brings up the issue of deciding which dairies would be permitted to expand at the advantage of using another farm's acreage for waste disposal.

Forest Land Application: The possibility of using Tillamook regional forests for land treatment and ultimate disposal of the digester effluent may be an attractive option for both its technical feasibility and economic benefits. This alternative would eliminate the need for dairymen to handle and manage wastewater backhauled to their farms. There are about 160,000 acres of private forest lands within Tillamook County, and the Tillamook District office of the Oregon State Forestry Department manages another 250,000 acres around the county. Identification of separate forest areas that could be practically used for land treatment have not been made for this study. Although the technique of irrigating agricultural lands with municipal wastes is a well studied and widely utilized method across the United States, the use of forest land for treatment and disposal of wastewaters by irrigation is a method as yet little used by municipalities or industry. The problem of determining appropriate application rates of waste nutrients to forest biosystems is a complex one and less straightforward to predict the assimilation of nitrogen and other waste constituents as with agricultural crops and soils. However, the technique has been shown to be a safe and economical method for waste treatment in comprehensive studies done in Pennsylvania, Georgia, Michigan, and Washington (Urie, *et. al*, 1985). Research began in 1973 at the University of Washington and full scale operations of application of municipal wastes to forest lands have been or are being practiced in Washington State by municipalities as diverse as Seattle, Bremerton, Tacoma, and Snoqualmie Pass. Juvenile reforested plantations, Christmas tree plantations, and pulp/energy wood plantations are the preferred kinds of forest type systems, while old growth and clearcuts are the most difficult areas to manage. Clearcuts pose the problem of competition to replanted saplings by herbaceous overgrowth promoted by fertilization. Old growth stands assimilate only small amounts of added nitrate & ammonia, and hence must be irrigated at a low rate or require the pretreatment of effluent for nitrogen reduction. Juvenile stands and open forests with vigorous herbaceous understories have provided the highest nitrogen assimilation. The maximum rate of assimilation in Douglas-fir plantings in Washington has been 778 lb-N/acre per year. Grass accounted for 49% of the nitrogen uptake. Growth in Douglas-fir seedlings has been measured to increase by 40% in height and 75% in diameter over controls, while spruce and pine species have shown 80% to 100% increases of growth by receiving wastewater irrigation. Application methods are either by installation of sprinkler systems or by use of mobile spray-rig vehicles. Sprinkler systems are generally the most expensive type to install and operate in forest lands, with construction costs ranging from $1,500 to $4,000/acre and operating costs ranging from $280 to $560/acre per year. All-terrain application vehicles equipped with a sludge cannon to spray wastewater 100 feet and a delivery capacity of 2,500 gallons/hour cost $150,000. Using spray vehicles requires clearing and grading access roads as part of the system's initial construction costs. No documented wildlife health hazards have been associated with forest irrigation. Human health risks from such systems, when designed for adequate nitrogen assimilation, are presumed to be even lower than for similar systems using agricultural crops.

At this time, the economic potential for the sludge solids and the most suitable technology for nitrogen control are still being evaluated. Preliminary estimates concerning the options of backhauling all the waste to originating farms, capturing sludge solids for their commercial value, a hypothetical lagoon treatment system, and forest application system and the impact these scenarios might have on the economic feasibility of the project will be included in the following sections.

TRUCKING COST ESTIMATES

One of the most significant factors affecting the economic feasibility of a Tillamook Dairy Waste Treatment Facility is the trucking cost involved in moving wastes from so many individual dairies. Trucking will account from 49% to 65% of the digester annual operating costs. In order to calculate the annual costs of trucking it is first necessary to determine the average cost per ton for delivering the total raw waste solids to the anaerobic digester. To arrive at a single value several assumptions need to be made about the hauling capacity of the truck fleet and its operation, as well as the probable site of the treatment facility. Due to the importance that hauling costs play in financial and managerial decisions to be made about this project, to arrive at as accurate an account as possible of trucking costs has required a complicated method of calculation. This section summarizes the assumptions and methods used in projecting hauling costs and the scenarios to be considered for the rest of this study.

Assumptions & Method

In order to determine how many trucks are required and how much it will cost to haul an assumed daily volume of dairy wastes, it is necessary to correlate truck loads, distances involved, and the time required to deliver those loads. The topics in this section are in reference to the trucking cost worksheet (table 2) used to estimate one of the possible project scenarios.

Truck Assumptions: It is assumed that large tanker trailer semi-trucks will be used for hauling the dairy wastes. These rigs have a hauling capacity of 48,000 pounds ('lb/truck'), and the self-pumping capability to load or unload in 15 minutes. The capital cost per truck and trailer is assumed to be $120,000 ('$/truck'). The hourly rate for operating the vehicles, both when on the road or idle for loading and unloading, is assumed to be $40 per hour ('$/hr'). This rate includes averaging in driver wages, fuel costs, maintenance, insurance, licensing, and miscellaneous costs.

Operational Variables: It is assumed that trucks will be able to average 30 miles per hour on Tillamook County roads. It is assumed that the turn-around time, or idle time needed to load and unload is a half-hour ('hrs-idle load/unload'). In making the assumption that there will necessarily be a backhauling of effluent, the total load/unload time is one hour. It is assumed that trucks will operate two shifts per day, approximately 16 hours total (12 to 18 hours in some cases).

Hauling Calculations: By multiplying the total waste assumed per cow times the number of cows per dairy times the mileage of that dairy from the project site, a value of pound*miles ('lb*mi') for that dairy is determined. Summing the individual 'lb*mi' values within a range of given distance from the site provides the 'sum farm lb*mi' that must be trucked per day. Multiplying the 48,000 lb capacity per truck times the average miles per hour it can travel times the number of hours per day it will be on the road ('hrs-run/day') gives the 'lb*mi/day' per truck. Dividing the 'sum farm lb*mi' by the 'lb*mi/day' per truck determines the number of trucks per day needed to haul the total waste within the assumed range.

Loading Calculations: The number of total loads per day that needs to be handled within a given range is the pounds of total waste in that range divided by the 48,000 lb capacity per truck load. The total loads per day multiplied by the load/unload time indicates the total 'truck hrs idle' per day required to handle all the wastes.

Table 2 - Trucking Cost Estimates

%TS=lbs 7%=217.3
Total Waste 10%=150
13%=115
20%=75

Tillamook County Dairy Waste
100% Collection - 100% Cow#'s

Parameter	Values Per Milk Cow		mi-5	Tillamook mi-10.5	<sum<	Cloverdale	Nehalem	Totals
			Sum Totals per Range lb/day					
Average weight per equivalent milk cow	1400	lbs						
Total waste (including etc.)	217.30	lb/day	1601936	2034797	3636733	1576512	435593	5648838
COD (Chemical Oxygen Demand)	11.37	lb/day	83820	106469	190288	82489	22792	295570
TKN (Total Kjedahl Nitrogen)	0.57	lb/day	4202	5337	9540	4135	1143	14817
K (Potassium)	0.33	lb/day	2433	3090	5523	2394	662	8579
TVS (Total Volatile Solids)	14.50	lb/day	106894	135778	242672	105198	29066	376936
TSS (Total Suspended Solids)	15.00	lb/day	110580	140460	251040	108825	30069	389934
Mg-TS/d			50	64	114	49	14	177
#Cows			7372	9364	16736	7255	2005	25996
No. Farms			53	65	118	58	15	191
Assumptions								
48000 lb/truck								
30 mi/hr								
hrs-run/day			2.7	5.0		4.0	1.1	
mi/d-truck			81	150		120	34	
lb-mi/d-truck			1946045	3588014.7		2871462	819370	
Hauling								
sum farm-lb*mi			5838134	21528088		8614387	819370	
total loads/day			33.4	75.8		32.8	9.1	118
1 hrs-idle load/unload								
hrs idle/truck			11.1	12.6		10.9	9.1	
truc hrs idle/day			33.4	75.8		32.8	9.1	
trucks-req'd			3	6		3	1	
Costs								
120000 $/truck								
40 $/hr								
capt'l $			360000	720000		360000	120000	1200000
operating $/day			1659	4227		1792	409	6427
Manure Handling								
$/wet-ton			2.07	2.32		2.27	1.88	2.28
$/Mg-TS			33.05	37.08		36.28	29.93	36.31

Trucks Required: Dividing the total 'truck hrs idle' by an integer value, representing full trucks, determines the number of hours idle per truck ('hrs idle/truck'). The 'hrs-run/day' per truck is adjusted so that the number of trucks required for hauling is the same integer value as that required for loading. If the sum of hours required for hauling and hours required for loading/unloading is much more than 16 hours, another truck is presumed necessary and the time allowed per truck adjusted accordingly.

Cost Calculations: Capital costs are simply the product of the number of trucks required and the $120,000 price per truck. Daily operating costs are a product of the sum hours per day per truck and the $40/hr rate times the number of trucks required. The cost of manure, in terms of dollars per metric ton of total solids ('$/Mg-TS') delivered to the anaerobic digester, is the daily operating cost divided by the amount of total solids assumed being hauled.

Method Verification: Information obtained from two different trucking operations has allowed for some measure of comparison and verification of the trucking cost estimate scheme used by this study. 'Biogro' is a sludge hauling operation run as part of a municipal waste treatment plant for Salem, Oregon (Willow Lake Waste Treatment Plant, Keizer,Oregon). 'Unisyn' (Universal Synergetics,Inc., Seattle, Washington) is a demonstration project on Oahu, Hawaii hauling poultry manure for an anaerobic digester system. Biogro uses tanker rigs fitting the assumptions mentioned above and delivers a 4% slurry to area farmland with an average round trip distance of 23 miles. Unisyn uses 44,000 lb capacity hopper dump-trailer rigs hauling a round trip distance of 75 miles.

Figures 6 & 7 show how well trucking cost estimates generated for various scenarios in this study approximate curves which reasonably fit to include the actual data of the two trucking operations. The average cost per load increases linearly as the average round trip distance increases (fig. 6). The cost per mile decreases exponentially as the average round trip distance increases (fig. 7). Despite the care given to estimating trucking costs as accurately as possible, the Biogro figure indicates that values determined by the method used for this study may be on the optimistic side of probable costs, while the Unisyn figure is slightly below the projected costs made for this study.

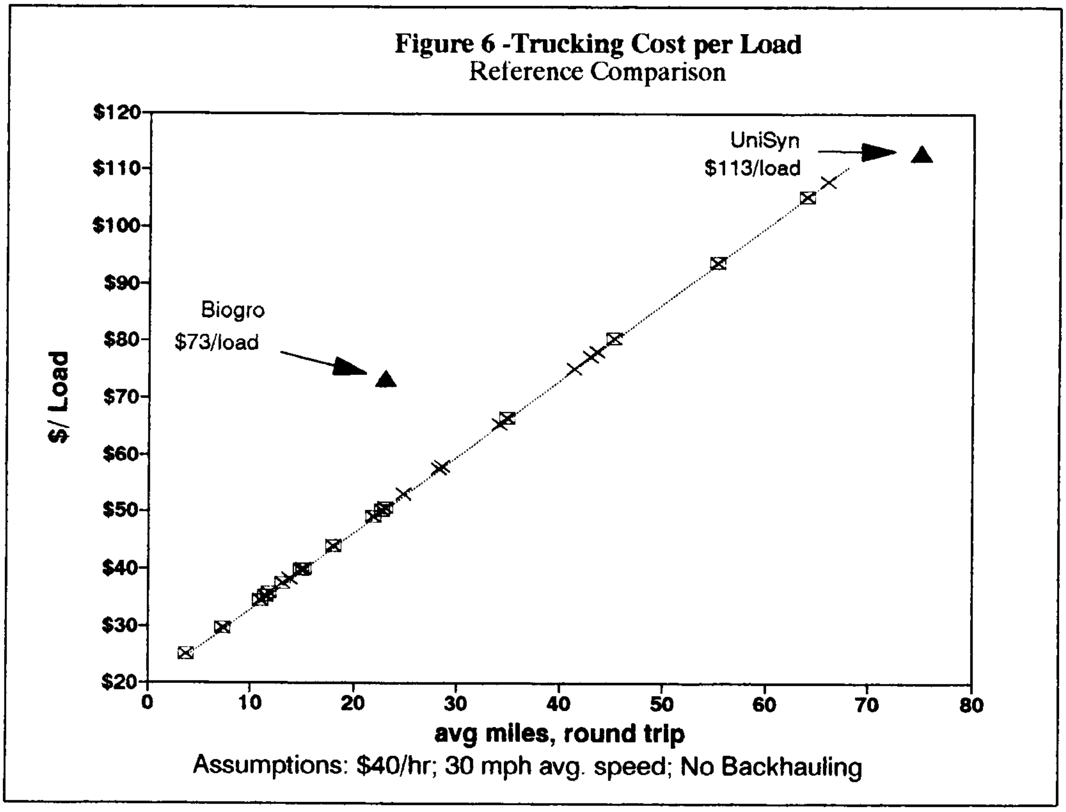


Figure 6 -Trucking Cost per Load
Reference Comparison
UniSyn
$113/load
Biogro
$73/load
$/ Load
$120
$110
$100
$90
$80
$70
$60
$50
$40
$30
$20
0
10
20
30
40
50
60
70
80
avg miles, round trip
Assumptions: $40/hr; 30 mph avg. speed; No Backhauling

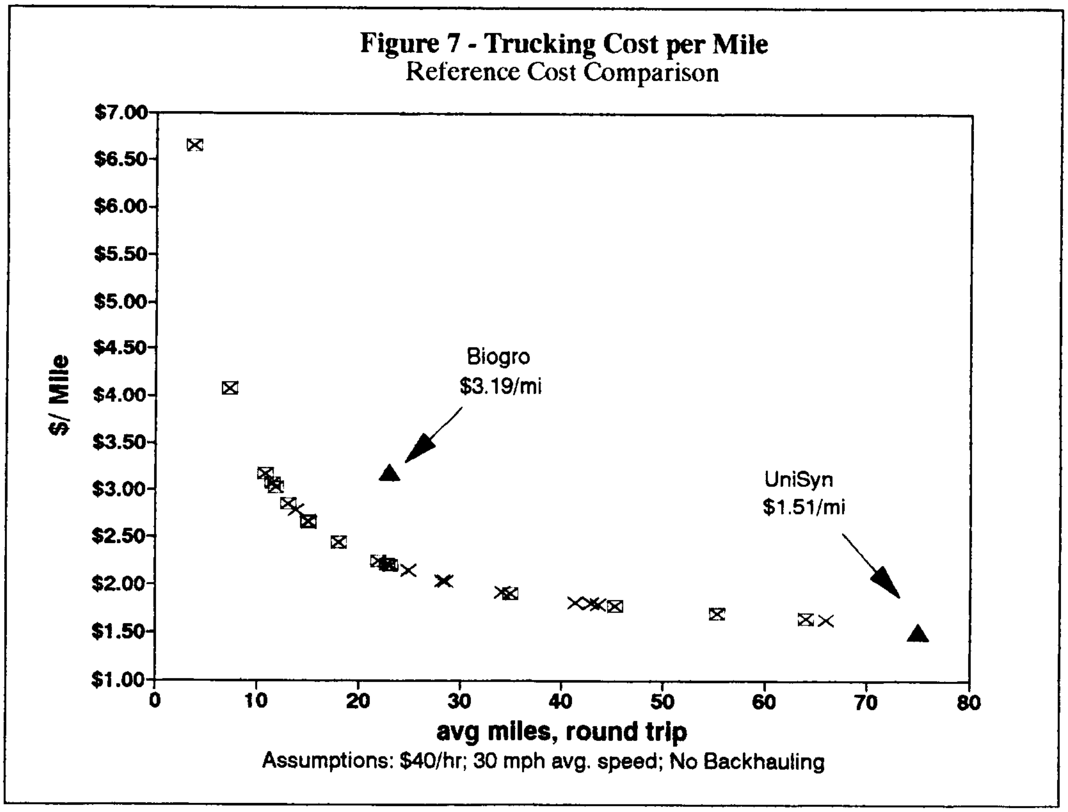


Figure 7 - Trucking Cost per Mile
Reference Cost Comparison
Biogro
$3.19/mi
UniSyn
$1.51/mi
$/ Mile
$7.00
$6.50
$6.00
$5.50
$5.00
$4.50
$4.00
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
0
10
20
30
40
50
60
70
80
avg miles, round trip
Assumptions: $40/hr; 30 mph avg. speed; No Backhauling

Trucking Scenarios

Given the above assumptions with regard to estimating trucking costs, there remain four more variable factors which must be assumed. These factors concern fundamental decisions that will need to be made in directing the operation and scope of the project. The assumptions that are made about these factors lead to the various scenarios to be considered by this report. The four factors are as follows:

Site of Treatment Plant(s): At this time, the primary project site is the Tillamook Industrial Park on the outskirts of the city of Tillamook. There is ample acreage available there for construction of the anaerobic digester facility and possible storage/nitrogen reduction lagoons. Existing and prospective industrial enterprises at the park could be potential customers for the natural gas or excess thermal energy (i.e. hot water) produced by the plant. Another possible site could be land near the Tillamook Creamery, which might realize an economic benefit from utilizing energy generated by the plant. When assuming a low raw waste TS concentration (7%), there appears to be a slight economic advantage for operating treatment plants at separate locations as compared to a single, all-county facility. Cumulative savings made on trucking due to shorter distances traveled to separate local sites compensate for the extra expenses involved for labor and maintenance and construction of multiple plants, when compared to a single plant (figure 8). Therefore with respect to trucking costs; 'worst', 'best', and 'most likely' scenarios are as follows (Note that 'Annual Operating Costs' are gross costs prior to any economic return on the value of electricity or fertilizer.) :

Worst Case: This scenario would have the wastes of all county farms delivered to a single plant built at the primary Tillamook location. (However at 13%-TS, three plants are slightly more expensive; see "Waste Solids Concentration" below.)

Best Case: A second scenario would posit three separate dairy waste treatment plants to serve Nehalem, central Tillamook, and Cloverdale area dairies. As previously indicated in, there are 118 dairies within a 10.5 mile range of the central Tillamook site, representing 64% of the county cow population. There are 58 dairies and 28% of the county herd size within 10 miles of Cloverdale, and 15 dairies and 8% of the cow population within 5 miles of Nehalem.

Most Likely Case: Considering that a separate Nehalem digester system would be serving such a small percentage of Tillamook County dairies, to simplify management of the project, a third scenario would entail two plants. One system to serve south county dairies and the main Tillamook plant would serve central and north county dairies.

Herd Size: One scenario is to use the current herd size numbers (100% Cow#'s) to establish a baseline set of estimates assessing the feasibility of the project given the status quo of area dairies. A second scenario is to assess the project feasibility if the county herd size were to double (200% Cow#'s), as desired for meeting the Tillamook Creamery's expanded production capacity.

On-Farm Manure Management: There are two variables to consider with regard to manure management, collection efficiency and waste solids concentration.

Collection Efficiency: This study presumes a consistent average daily supply of manure solids to be delivered 365 days a year to the anaerobic digester. One scenario is to assume an intensive confinement-collection scheme whereby 100% of the total possible manure is to be treated. This scenario is impractical but it does provide upper limit estimates of the project's potential and a margin of possible high end costs. A second scenario assumes 50% collection of the total possible manure, thereby more realistically allowing for daily or seasonal unavailability of all possible manure due to pastured animals. (When looking at scenario figures it should be kept in mind that 100% collection of 100% cow#'s and 50% collection of 200% cow#'s yield the same amount of total solids to handle. Hence trucking costs and plant size for the two scenarios are the same.) Seasonal fluctuations in manure collection and supply and its effect on trucking costs and digester performance have not been modeled for all-county scenarios. A comparison on the effect of seasonal availability of manure has been estimated for scenarios regarding the phased expansion of an initial central Tillamook site (see section on "Tillamook Plant Size").

Waste Solids Concentration: The significance of the assumed total solids concentration of the raw waste delivered to the anaerobic digester design was first mentioned in the section "Physical Plant Size". The raw waste total solids concentration also is of utmost importance for estimating the hauling costs. Preliminary estimates made in compiling this study indicate that using tankers to haul manure in slurry form is more economical than utilizing dump trucks to haul manure taken from 'solids' storage bins. Furthermore, the probable backhauling of digester effluent will necessitate using tanker trucks.

To best facilitate trucking operations it is presumed a uniform method of on-farm storage of wastes in slurry tanks will be adopted by participating dairies. Many dairies already have such facilities, and could begin participating with minimal capital improvements for necessary modifications. It has not been possible for this study to accurately assess how many dairies would require major changes to undertake slurry storage. Therefore an estimate of capital costs required for construction of new storage tanks has not been included in the economic scenarios that follow. It is presumed that dairymen know better than anyone what it would cost them to set up storage tanks as part of their operations. The need for careful water management to keep slurry concentrations as high as practical must be emphasized in order to minimize annual operating costs (figure 9). Dairy men can manage to aim for high TS concentrations by conscientious water management. For example diverting rain runoff with gutters and ditches and segregating milk parlor wash water from the manure storage are steps that could be taken to maximize slurry concentrations. With respect to trucking, three basic scenarios could be the following:

Worst Case: Slurry concentrations are typically about 7% total solids. One scenario is to presume the total raw waste will be at least 7%-TS.

Best Case: This scenario presumes there will be diligent water control in manure collection providing a 13%-TS slurry, which is about as thick as can be readily pumped. (In this case operating a single all county plant or two plants, instead of trucking to three sites, is more economical.)

Most Likely Case:: A third scenario presumes an intermediate average slurry concentration of 10%-TS.

A comparison of each case scenario and the effect slurry total solids concentrations have on *net* annual operating costs in terms of cost per cow is shown in figure 10. Figures 11 and 12 show similar comparisons of annual operating costs and cost per cow estimates vs total solids for start-up/expansion scenarios (explained in the section "Tillamook Start-up & Expansion").

Figure 8 - Digester Sites Comparison
Separate vs. Combined Plants

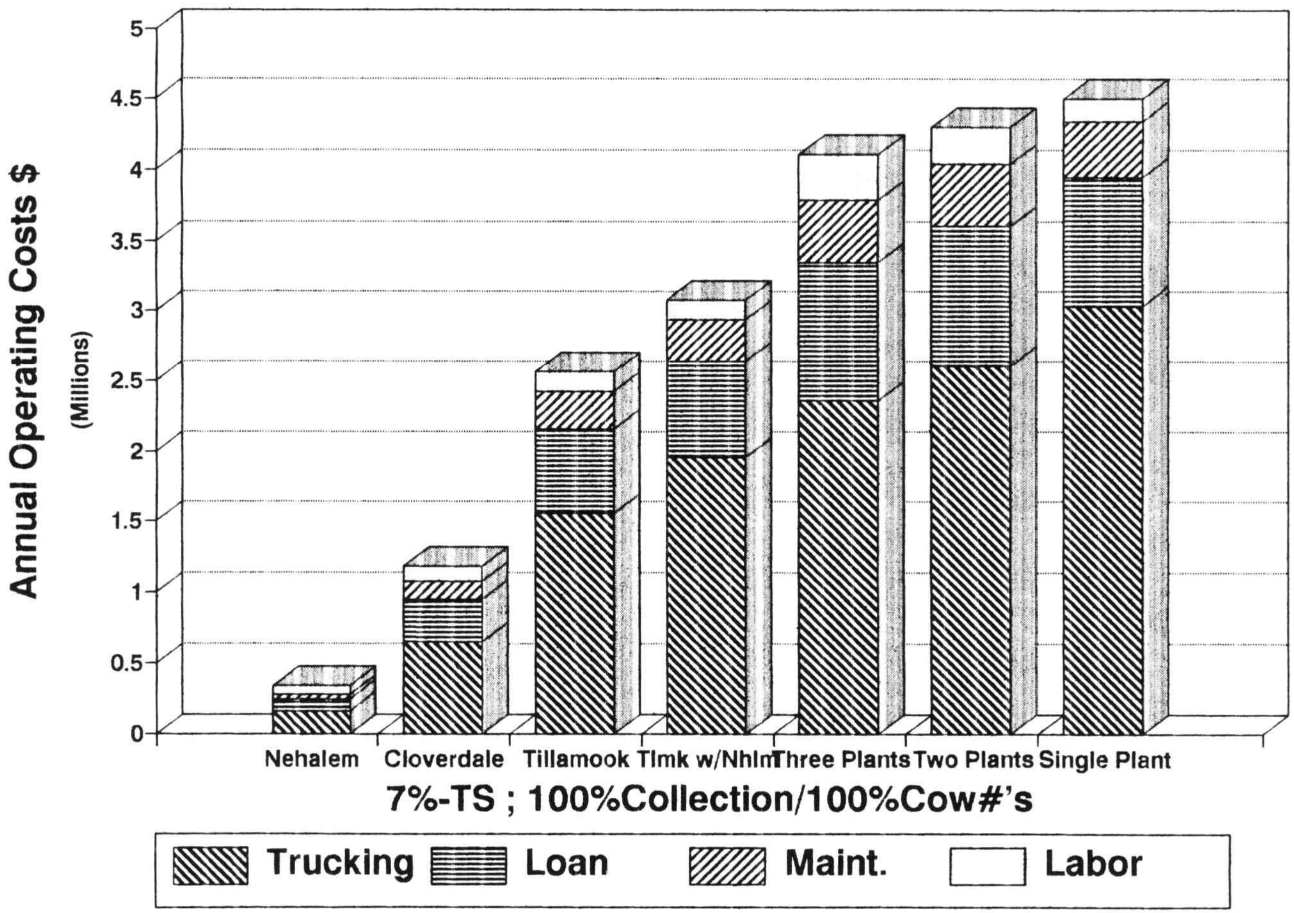


Figure 9 - Annual Costs & Slurry Solids
7%-TS vs 13%-TS

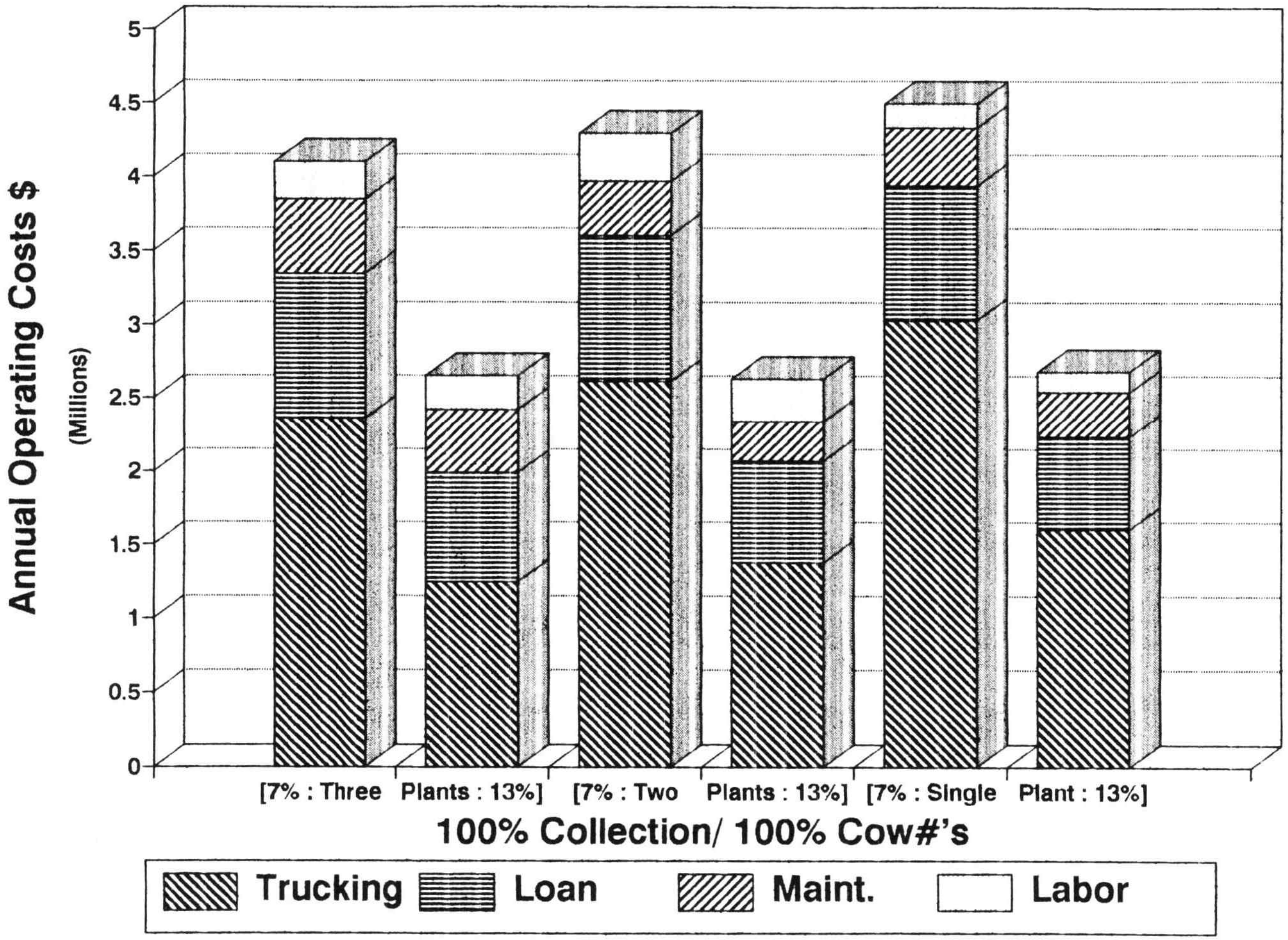


Figure 10 - Digester Cost per Cow
Total Solids Concentration Scenarios

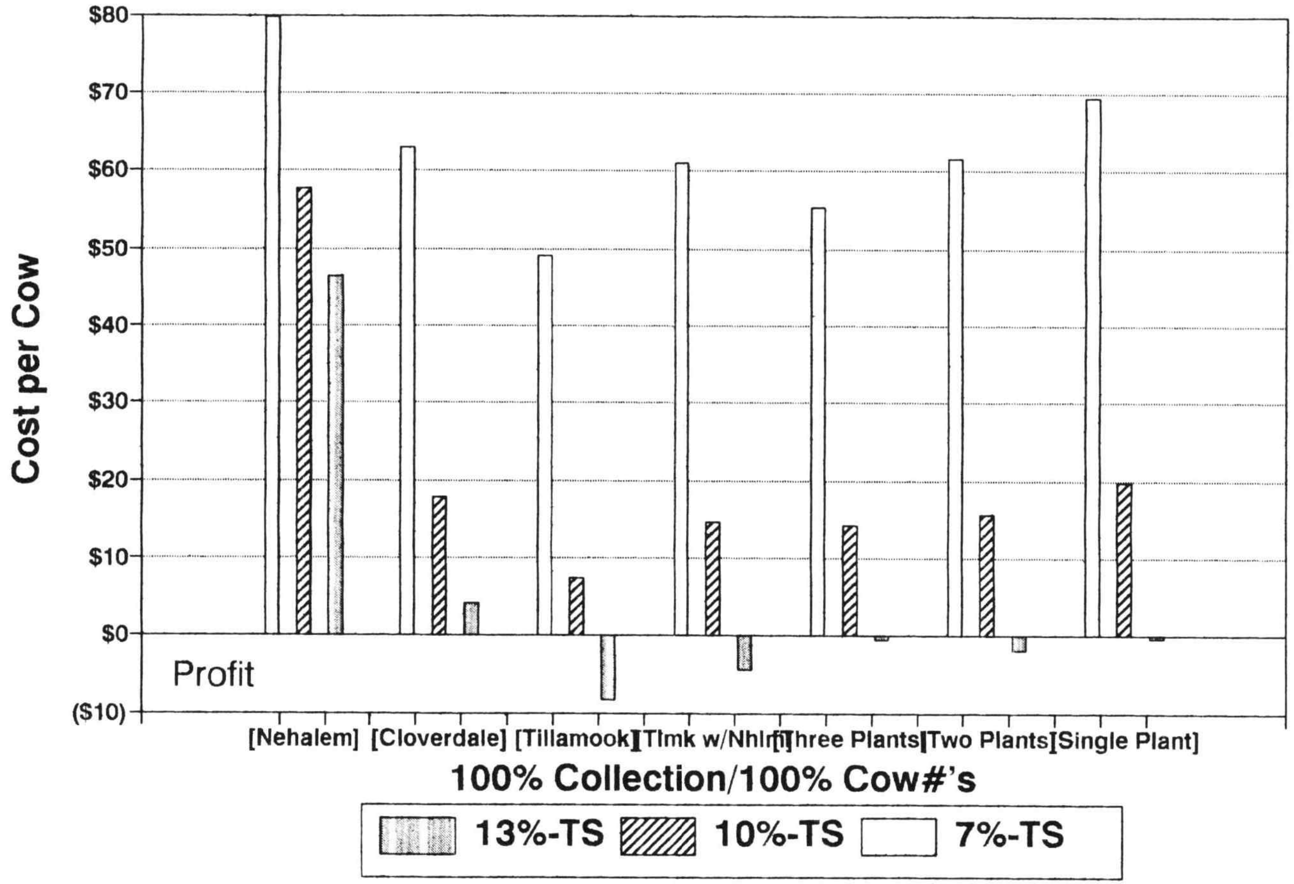


Figure 11-Phased Expansion Annual Costs
Annual Operating Costs

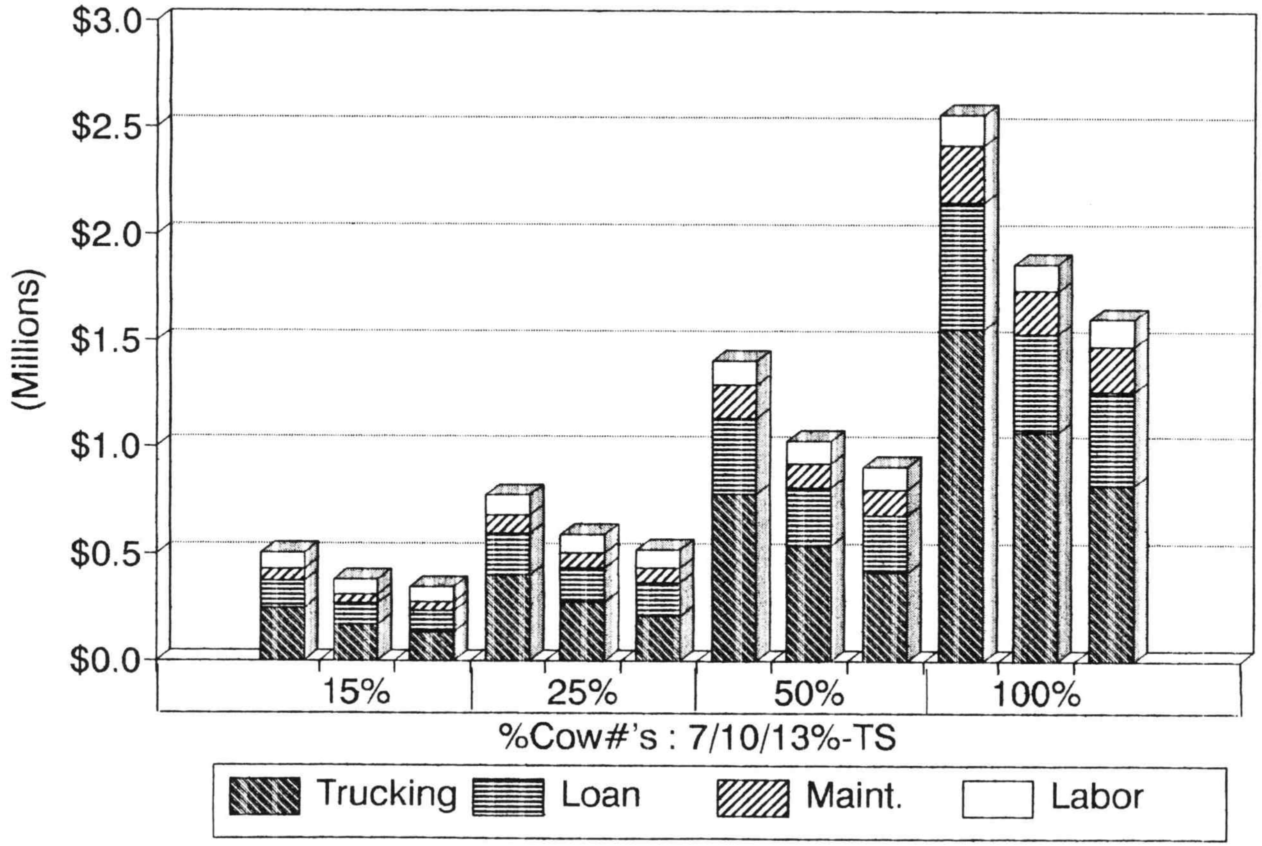
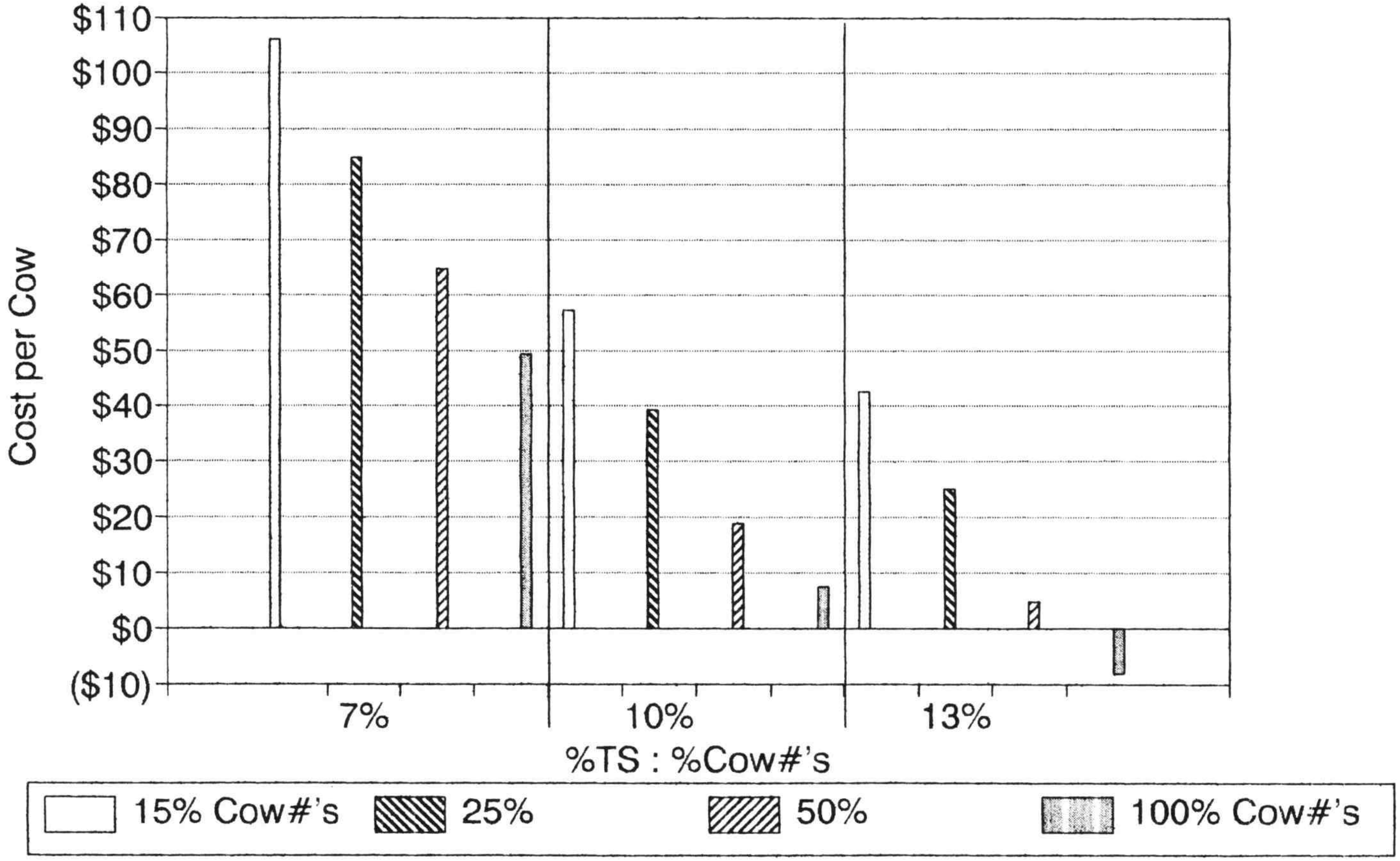


Figure 12-Phased Expansion Cost per Cow
Tillamook Phased Expansion



ECONOMIC FEASIBILITY

To be able to finally assess the feasibility of a Tillamook County Dairy Waste Treatment Facility a few 'bottom line' values need to be deciphered from the many possible scenarios. In this section, key economic assumptions are discussed which are needed to complete the picture of possible project scenarios. A summary of results and a brief explanation of significant values estimated for particular scenarios end this section. Perhaps two values can best summarize the economic viability of the Tillamook MEAD project. These indicators are:

- Net Cost per Cow: this value represents the annual expense for waste treatment dairymen can expect to pay in support of the system.
- Cost per Kilowatt Hour: this values represents the cost of production of electricity. It indicates the 'break even' price of electricity needed for the digester system to pay for itself (without other income benefits).

In order to calculate these values there remain several more factors not yet discussed which affect a project scenario's economic outlook.

Key Variables

To complete the picture of possible system parameters, the following economic and operational factors are considered.

Economic Factors: There are two variables independent of any system design assumptions that ultimately affect feasibility.

Selling Price: The price that can be expected in return for sale of electricity generated by the plant is, with trucking costs, the most significant of all variables involved in this study. Current events and future demands in the energy market need to be considered in evaluating the long-term prospects of a methane-electrical generation plant. Such speculation goes beyond the scope of this report. However, renewable resources are a priority in regional power supply plans and the value of new power sources can be expected to be higher than Northwest power rates have historically been. As of this writing, a definite price for electricity has not been established, but a probable range can be assumed. The effect different buy-back rates have on a project scenario is shown in figure 13. The graph indicates that an all-county system with a collection efficiency of 50% of the manure from 100% of the current herd size has a production cost of \$0.067/kWh. The cost of production decreases as the size of the plant increases with herd size and collection efficiency, and the prospect of breaking even or realizing a profit increases at rates higher than \$0.06/kWh.

Worst Case: Initial indications from the Tillamook People's Utility District when researching this report set the buy-back rate at 4.7 cents per kilowatt-hour (\$0.047/kWh).

Best Case: The 'break-even' price for fully developed, all-county system scenarios is between \$0.06/kWh and \$0.07/kWh. As electrical rates in the Northwest increase to levels comparable to the rest of the country, within a few years a price greater than \$0.06/kWh could be anticipated,

Most Likely Case: The most recent information from the PUD allows for an assumption of \$0.060/kWh as the energy value.

Interest Rate: A discussion about the prospective sources of funding for a large scale dairy waste treatment facility is a topic beyond the scope of this study. However, in order to estimate total annual costs, the cost of debt repayment needs to be included in an account of project feasibility.

The annual cost of capital has been calculated assuming the capital-recovery formula,

$$A = P\,(i\,(1+i)^N)\,/\,((1+i)^N - 1)$$

where: 'A' is the annuity; 'P' is the total capital cost; 'i' is the interest rate; and 'N' is the number of years for debt recovery. For this study, the loan is assumed to be for 30 years. A comparison of the effect between 'worst case' assumptions of a $0.047/kWh selling rate, and 20 year loan, and a 'most likely' $0.060/kWh selling rate and 30 year loan period, and what different loan rates have on scenario costs is shown in figure 14. The graph shows that project costs are strongly effected by the assumed loan period and electrical rate, with best case values $12 to $14 per cow per year less than in worst case scenarios. A three point difference in interest rates changes the yearly cost per cow by only about $5.

Worst Case: If the availability of money is 'tight' by the time this project is financed, an interest rate of at least 11% could be expected.

Best Case: There have been indications that an interest rate as low as 8% may be available through the Oregon Department of Energy 'Small Scale Energy Loan Program'.

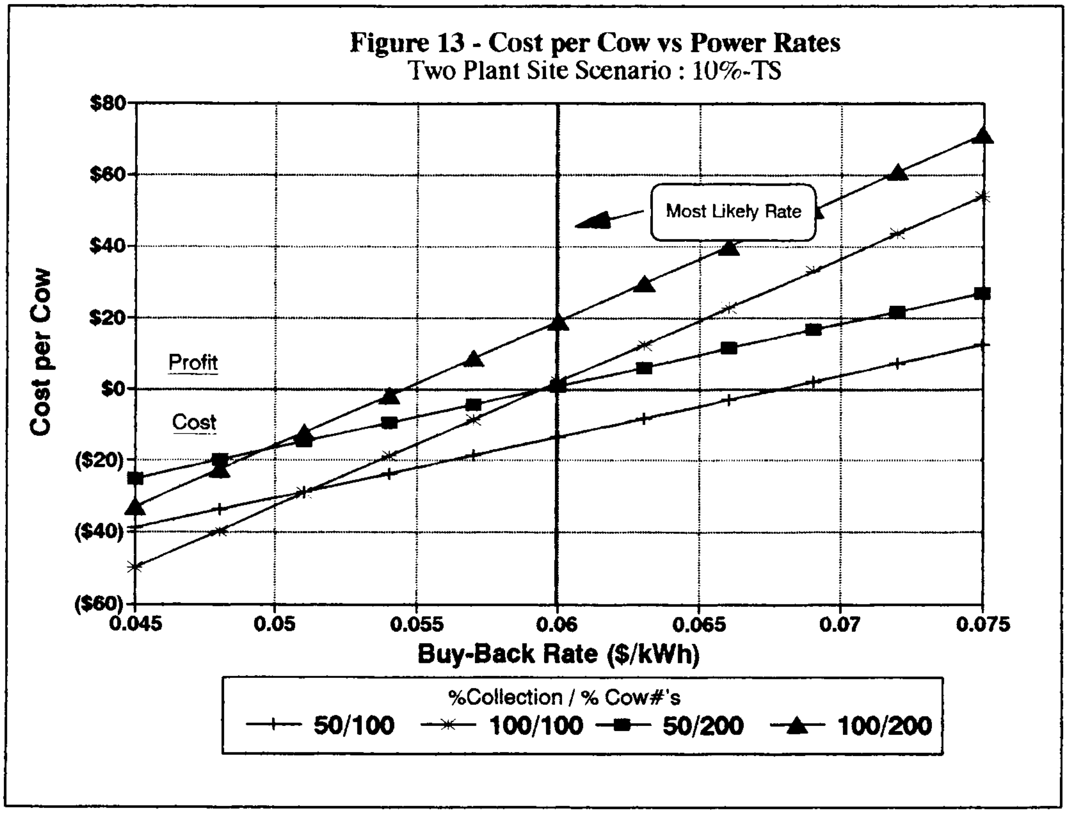


Figure 13 - Cost per Cow vs Power Rates
Two Plant Site Scenario : 10%-TS
Most Likely Rate
Profit
Cost
Cost per Cow
$80
$60
$40
$20
$0
($20)
($40)
($60)
0.045
0.05
0.055
0.06
0.065
0.07
0.075
Buy-Back Rate ($/kWh)
%Collection / % Cow#'s
50/100
100/100
50/200
100/200

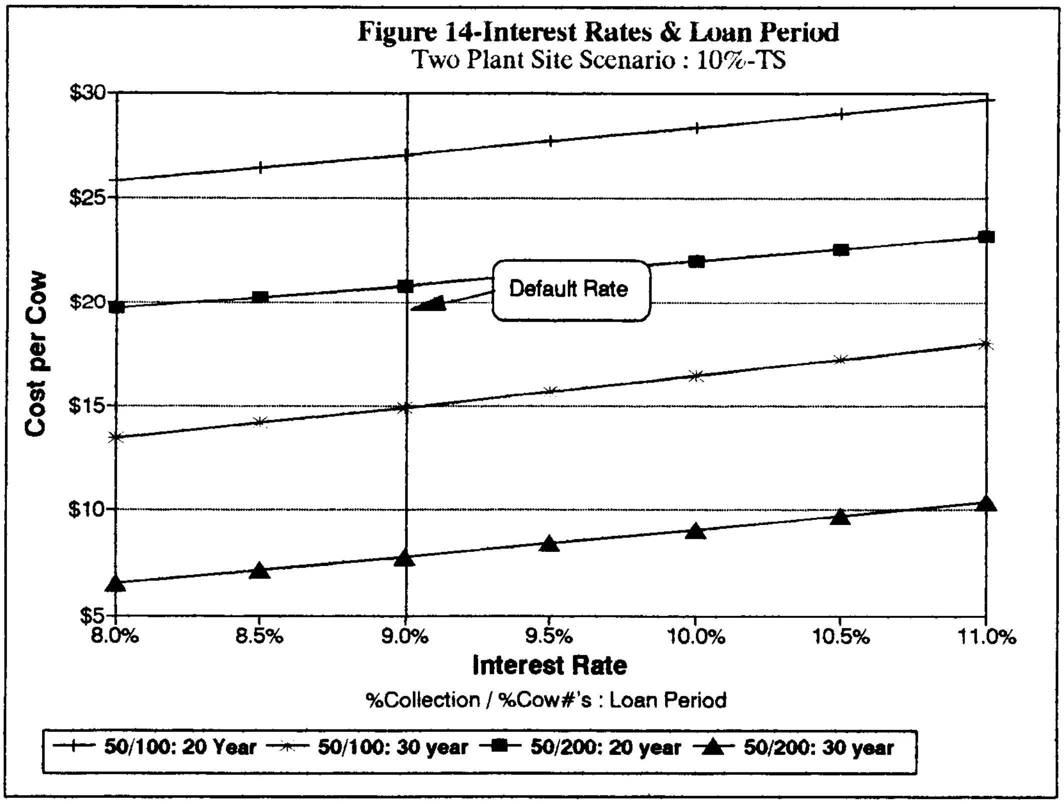


Figure 14-Interest Rates & Loan Period
Two Plant Site Scenario : 10%-TS
Default Rate
Cost per Cow
$30
$25
$20
$15
$10
$5
8.0%
8.5%
9.0%
9.5%
10.0%
10.5%
11.0%
Interest Rate
%Collection / %Cow#'s : Loan Period
50/100: 20 Year
50/100: 30 year
50/200: 20 year
50/200: 30 year

Most Likely Case: Initial indications set a probable interest rate at 9%. This is the default rate used for scenarios other than those in figure 14.

Operational Factors: For sake of completeness, the following factors need to be addressed among the possible design scenarios.

Nitrogen Treatment: Trucking costs have been calculated assuming a backhauling of all digester effluent to originating farms. The nitrogen reductions required for farm land application assuming the four possible collection and herdsize combinations being considered is outlined in table 3. The column '% MaxApplied to Pasture' indicates to what extent the uncollected fraction of total nitrogen assumed generated per day meets the maximum annual application rate for the 35,000 acres available. Table 3 accounts for a 20% reduction of NH_3-N assumed volatilized in the raw waste collected during the processes of on farm storage and handling for transport. The 'Acres for Application' column is an estimate of the farm land required for nitrogen treatment of the digester effluent without any secondary treatment, assuming the uncollected manure is already applied to the land and accounting for 20% ammonia volatilization. '%Reduction Required of Effluent N' in the final column estimates the percentage of total nitrogen remaining in the collected manure that must be removed before meeting the maximum application rate for the acreage available. Lagoon Storage requirements and costs for the various Tillamook scenarios are summarized in table 5. In this table, two options for nitrogen reduction are evaluated. The lagoon system modeled is assumed to be a facultative type, with a depth of 16 feet (including excess capacity for six months of rainfall). Dissolved oxygen is supplied to the aerobic zone by surface aerators, algae photosynthesis, and surface transfer with the atmosphere. For a six-month storage capacity lagoon the assumption is made that a 80% reduction of NH_3-N is possible, and for a four-month lagoon capacity a 60% reduction is possible. Table 5 includes estimates on how much farm land or forest land area would be required to dispose of the lagoon effluent, accounting for nitrogen removed also by the fertilizer/solids capture process. The cost per cow of a lagoon system to handle all the county's dairy wastes range from $2 to $8/cow per year.

<u>Effluent Utilization:</u> The economic potential of the sludge solids is evaluated in table 6 based on the effluent volume, total solids, and nitrogen captured estimates outlined in table 4. The options of capturing either 30% or 40% of the total solids in the digester effluent, valued at either $100/ton or $200/ton is presented in table 6. Belt filter dewatering has become a popular and cost effective process for dewatering sludges. The values outlined in the table assume using a belt-filter facility processing manure for both entire county and start-up/expansion scenarios. The potential is there for a positive economic return if there is a market for the digester sludge as bedding and compost products. Profits may range from $6 to over $100/cow per year. This component of the overall dairy waste treatment facility could play a significant part in reducing overall treatment system costs, or even to allow a profit. The caveat is, of course, in establishing that there is a reasonable market demand for the product. To do so will require a study by marketing experts, such as the waste treatment specialists previously mentioned, Unisyn, Inc.

Table 3 - Farmland & Nitrogen Application

Reductions & Acreages Required; Expansion & All County Scenarios

%Collect/ %Cow#'s Expansion	Total N Produced (lb/day)	Applied to Pasture	%MaxAppl to Pasture	TN Collected (lbs/day)	TN col'td w/20 NH3 reduction	Acres for Application	lbs to reduce of Collected N	%Reduction Required of Effluent N
100/15	1431	0	0%	1431	1345	2200	0	0%
100/25	2385	0	0%	2385	2242	3700	0	0%
100/50	4770	0	0%	4770	4484	7400	0	0%
100/100	9540	0	0%	9540	8967	14900	0	0%
All County								
50/100	14817	7409	35%	7409	6964	23800	0	0%
100/100	14817	0	0%	14817	13928	23100	0	0%
50/200	29633	14817	70%	14817	13928	47700	7648	52%
100/200	29633	0	0%	29633	27855	46200	6759	23%

[Assuming 220 lb-N/acre-year & 35,000 acres available for application]

Table 4 - Effluent Volume & Total Solids Captured

& Nitrogen Content for Commercial Fertilizer

%Collect/ %Cow#'s	Qeff (from dige (m^3/day	Total Solids (ton/day)	TN collected (lb/day)	% TS Captured	TS Captured (ton/day)	TN Captured @ 3%-N/TS (lb/day)	TN remaining in Effluent (lb/day)	TS remaining in Effluent (ton/day)	%TS Qeff	Storage (acre*ft)	
										4 mnth	6 mnth
Expansion											
100/15	180	20	1345	30%	6.0	357	987	14	7.0%	18	26
				40%	7.9	477	868	12	6.0%	18	26
100/25	294	40	2242	30%	11.9	715	1527	28	8.6%	29	43
				40%	15.9	954	1288	24	7.4%	29	43
100/50	579	79	4484	30%	23.8	1430	3053	56	8.7%	56	85
				40%	31.8	1907	2577	48	7.5%	56	85
100/100	1149	159	8967	30%	47.7	2860	6107	111	8.8%	112	168
				40%	63.6	3814	5153	95	7.5%	112	168
All County											
50/100	899	68	6964	30%	20.4	1224	5740	48	4.8%	88	131
				40%	27.2	1632	5332	41	4.1%	88	131
100/100	1779	136	13928	30%	40.8	2448	11480	95	4.9%	173	260
				40%	54.4	3264	10664	82	4.2%	173	260
50/200	1779	136	13928	30%	40.8	2448	11480	95	4.9%	173	260
				40%	54.4	3264	10664	82	4.2%	173	260
100/200	3549	272	27855	30%	81.6	4896	22959	190	4.9%	345	518
				40%	108.8	6528	21327	163	4.2%	345	518

[Assuming 10%-TS; Expansion & All County Scenario]

Table 5 - Lagoon Storage Requirements & Costs

Land Application Required After NH3-N Reduction

%Collect/ %Cow#'s Expansion	Storage Capacity (days)	Lagoon Volume (acre*ft)	Lagoon Surface (acre)	Assumed % NH3-N Reduction	%TN Remaining Overall	Farm Land Required (acres) (@ 220 lb/acre)	Forest Land Required (acres) (@ 775 lb/acre)	Total Capital Cost	Operational Annual Cost	Amortized Capital Cost	Annual Cost	Annual Cost per Cow
100/15	120	21	1.3	60%	48.31%	1831	326	94,000	3,311	9,150	12,461	$0.48
	180	34	2.1	80%	44.74%	1062	301	152,200	5,360	14,815	20,175	$0.78
100/25	120	34	2.1	60%	44.81%	1773	503	152,200	5,360	14,815	20,175	$0.78
	180	56	3.5	80%	42.41%	1678	476	250,700	8,828	24,402	33,230	$1.28
100/50	120	67	4.2	60%	44.81%	3546	1007	299,900	10,562	29,191	39,753	$0.76
	180	110	6.9	80%	42.41%	3356	953	492,400	17,341	47,928	65,269	$1.26
100/100	120	133	8.3	60%	44.81%	7092	2013	595,300	20,967	57,944	78,911	$1.52
	180	219	13.7	80%	42.41%	6712	1905	980,300	34,524	95,419	129,943	$2.50
All County												
50/100	120	104	6.5	60%	77.12%	18958	1892	465,500	16,395	45,310	61,705	$2
	180	171	10.7	80%	73.24%	18005	1622	765,400	26,957	74,501	101,458	$4
100/100	120	205	12.8	60%	54.23%	13332	3785	917,600	32,317	89,316	121,633	$5
	180	339	21.2	80%	46.49%	11428	3244	1,517,000	53,442	147,659	201,101	$8
50/200	120	205	12.8	60%	77.12%	37914	3785	917,600	32,317	89,316	121,633	$2
	180	339	21.2	80%	73.24%	36009	3244	1,517,000	53,442	147,659	201,101	$4
100/200	120	409	25.6	60%	54.23%	26664	7569	1,831,000	64,477	178,223	242,700	$5
	180	677	42.3	80%	46.49%	22855	6488	3,030,000	106,726	294,929	401,655	$8

[Assuming 10%-TS; All County Scenario]

Table 6 - Commercial Value of Captured Sludge Solids

Start-up/Expansion & All County Scenarios

%Collect/ %Cow#'s	Mg-TS/day ton/day	Value $/ton	% TS Captured	Ton/day Captured	Annual Worth $/year	Total Capital Cost	Opertion & Maint. Annual Cost	Amortized Capital Cost	Annual O&M Cost	Annual Net Return	Annual Net per Cow
100/15	18.02	100	30%	6.0	217,000	250,532	40,631	24,386	65,017	151,983	$61
			40%	7.9	290,000	270,600	55,966	26,339	82,305	207,695	$83
	20	200	30%	6.0	435,000	250,532	40,631	24,386	65,017	369,983	$147
			40%	7.9	580,000	270,600	55,966	26,339	82,305	497,695	$198
100/25	29.42	100	30%	9.7	355,000	288,979	71,456	28,128	99,584	255,416	$61
			40%	13.0	473,000	323,088	101,455	31,448	132,903	340,097	$81
	32	200	30%	9.7	710,000	288,979	71,456	28,128	99,584	610,416	$146
			40%	13.0	946,000	323,088	101,455	31,448	132,903	813,097	$194
100/50	57.92	100	30%	19.2	699,000	390,783	80,746	38,037	118,783	580,217	$69
			40%	25.5	932,000	464,062	113,981	45,170	159,151	772,849	$92
	64	200	30%	19.2	1,398,000	390,783	80,746	38,037	118,783	1,279,217	$153
			40%	25.5	1,864,000	464,062	113,981	45,170	159,151	1,704,849	$204
100/100	114.92	100	30%	38.0	1,387,000	616,374	154,251	59,996	214,247	1,172,753	$70
			40%	50.7	1,849,000	782,129	221,183	76,130	297,313	1,551,687	$93
	127	200	30%	38.0	2,774,000	616,374	154,251	59,996	214,247	2,559,753	$153
			40%	50.7	3,698,000	782,129	221,183	76,130	297,313	3,400,687	$203
50/100	61.5	100	30%	20.3	742,000	514,068	456,659	50,038	506,697	235,303	$9
			40%	27.1	989,000	637,278	779,659	62,030	841,689	147,311	$6
	68	200	30%	20.3	1,484,000	514,068	456,659	50,038	506,697	977,303	$38
			40%	27.1	1,979,000	637,278	779,659	62,030	841,689	1,137,311	$44
100/100	123	100	30%	40.7	1,484,000	894,121	906,721	87,030	993,751	490,249	$19
			40%	54.2	1,979,000	1,176,216	1,553,635	114,489	1,668,124	310,876	$12
	136	200	30%	40.7	2,969,000	894,121	906,721	87,030	993,751	1,975,249	$76
			40%	54.2	3,959,000	1,176,216	1,553,635	114,489	1,668,124	2,290,876	$88
50/200	123	100	30%	40.7	1,484,000	894,121	906,721	87,030	993,751	490,249	$9
			40%	54.2	1,979,000	1,176,216	1,553,635	114,489	1,668,124	310,876	$6
	136	200	30%	40.7	2,969,000	894,121	906,721	87,030	993,751	1,975,249	$38
			40%	54.2	3,959,000	1,176,216	1,553,635	114,489	1,668,124	2,290,876	$44
100/200	246	100	30%	81.3	2,969,000	1,770,123	1,810,808	172,297	1,983,105	985,895	$19
			40%	108.5	3,959,000	2,370,819	3,106,686	230,767	3,337,453	621,547	$12
	271	200	30%	81.3	5,938,000	1,770,123	1,810,808	172,297	1,983,105	3,954,895	$76
			40%	108.5	7,918,000	2,370,819	3,106,686	230,767	3,337,453	4,580,547	$88

[Assuming belt filter dewatering process 16 hr/day|365 day/yr]

The option for forest land application instead of returning system effluent to area farm land is evaluated in table 7, assuming the nitrogen reduction accomplished by the previous steps of 30% solids removal and four month lagoon storage. The cost estimates are modeled on a system using specially designed on-site sludge application vehicles. Estimating the cost of clearing brush and trees and grading rough access roads are included in the capital costs. Operational and maintenance costs include labor, diesel fuel for vehicles, vehicle maintenance, and site maintenance. The cost per cow for undertaking a forest application system range from $43 to $86 per year.

Energy Self-Sufficiency: The prospect of utilizing methane as a fuel for the project truck fleet, thus effectively making the entire treatment system energy self-sufficient, is worth considering. The technical feasibility of actually operating the trucking fleet on natural gas has not been researched for this report, but it is presumed possible. Rough estimates were made on the quantity of methane required to substitute for the diesel energy value consumed in trucking. The effect of utilizing the required quantity of methane for vehicle fuel instead of electrical production was modeled by including gas option 2 of the digester design, whereby calculations are made for processing the requisite quantity of methane by scrubbing and compressing for storage (figure 15). It appears that as fuel prices approach $2 per gallon, conversion of the trucking fleet to methane (natural gas) power will be an economical alternative. The cost per cow comparison shown in figure 15 shows that energy self-sufficiency can be a break even proposition as fuel prices reach $1.70/gallon for 10% and 13% raw waste total solids concentration scenarios. The values calculated for figure 15 and table 8 reflect the assumptions that the $40/hr default trucking rate is comprised of a $30/hr base rate for fixed costs and the balance of $10/hr represents fuel consumption at 10 gallon/hr valued at about $1.10/gallon. The economic assumptions in designing for energy self-sufficiency include additional capital costs of $2,000 per truck for fuel tank and equivalent gasoline engine conversions and added construction costs for methane processing. The effect of drawing off the requisite volume of methane for trucking reduces the daily electrical production and sales and hence increases the total annual net cost of operating the digester. With the digester system energy self-sufficient, the annual cost per cow ranges from $16/cow at 10%-TS and returning about $1/cow for 13% total solids scenarios.

Tillamook Plant Size: In addition to area dairy wastes, the primary Tillamook facility may also accept sludge solids from both the Tillamook Creamery and Tillamook City sewage treatment plants (STP). Including human wastes in the system presents regulatory complications for the ultimate disposal of system effluent. The impact of these additional solids upon the performance of the digester is minimal, as the combined mass of sewage sludge from both plants is only about 1 ton per day. This is only one or two per cent of the total solids the central plant is expected to process. (A rule of thumb postulates that the waste of a 1,000 dairy cows is comparable to that generated by a town of 10,000 people.) An average production of 0.77 Mg-TS/day is estimated for the creamery STP, and only 0.145 Mg-TS/day from the city STP. These numbers have been included by default for determining Tillamook digester scenarios.

Tillamook Start-up & Expansion: Besides the estimates projecting the size and cost of fully developed systems serving the whole county with both current herd size and expanded herd size scenarios, scenarios are also considered at the other end of the spectrum, for an initial central Tillamook plant developed in increments of phased expansion. The assumptions made for start-up scenarios include a 100% collection efficiency of manure of 15%, 25%, 50%, and 100% of the central Tillamook herdsize estimate of 16736 cow-units. An initial plant serving about 2500 cow-units would handle as much as 18 metric tons of total solids per day, compared to 115 metric tons for 100% of the area cow population. Table 10 presents basic digester scenarios for start-up and expansion. Estimated values for complete system phased expansion are also included in the tables along with the full scale scenarios. Estimates for possible forest land disposal of effluent was not made, on the presumption that the forest land option is not applicable until the quantity of wastes treated reaches all-county and expanded herd size proportions.

Seasonal Availability of Manure: The availability of manure will vary in the course of the year, as animals are kept in confinement during the wet winter months, and let out to pasture in the dry summer season. Systems must be designed to accept the maximum volume of wastes that can be expected to be available over the course of the year, even though for roughly half a year the plant will be 'oversized'. Table 11 shows how digester costs are effected by a plant operating at different collection rates in the course of the year, in contrast to the scenarios of table 10. The assumptions made in the estimates of table 11 include 100% collection of manure during the six months of the year animals are kept in confinement, and 50% collection the other half of the year. Herd size scenarios include 15%, 50%, and 100% of Tillamook area cows. The cost of trucking the manure per ton for the initial stages was assumed to be the same as estimated for trucking to all the dairies within a 10.5 mile radius of the Port of Tillamook. With the digester treating 50%

of the design waste volume, the assumption is made that the hydraulic retention time is doubled from 12 days to 24 days. The table shows annual estimates of a digester run at 50% or 100% collection for the entire year, and then the effective annual sum or averages of combining the two plant parameters. The nominal results are discussed in the following section.

Figure 15 - Energy Self-Sufficiency
Cost per Cow vs Fuel Prices

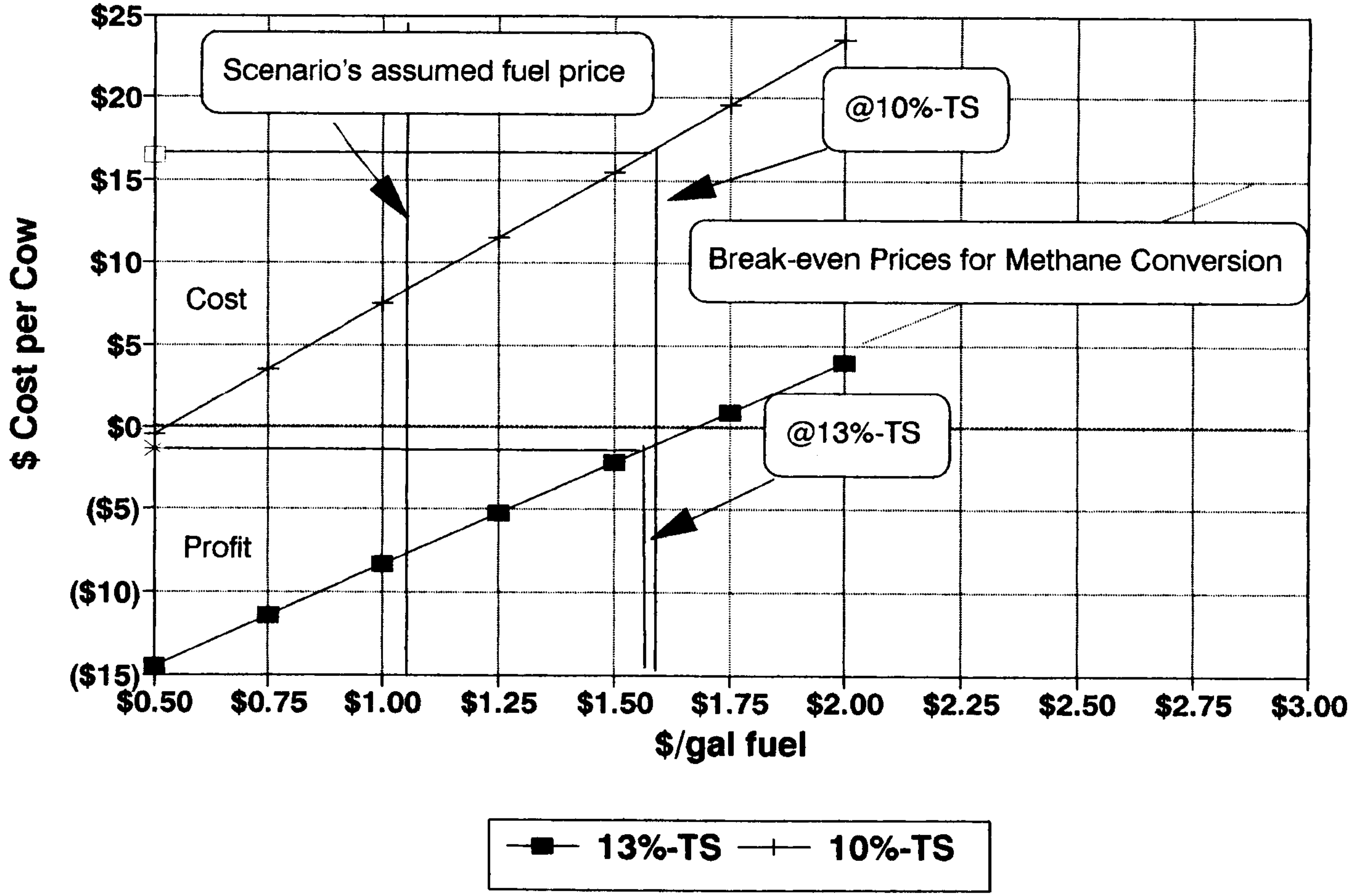


Table 7 - Forest land & Nitrogen Application

Acreages Required & Estimated Costs; All County Scenario

%Collect/% %Cow#'s	Collected (lbs/day)	Acres for Applicatio	Total Capital Cost	Operational Annual Cost	Amortized Capital Cost	Annual Cost	Annual Cost per Cow
50/100	4018	1900	2,439,260	882,310	237,429	1,119,739	$43
100/100	8036	3800	4,878,520	1,761,430	474,857	2,236,287	$86
50/200	8036	3800	4,878,520	1,761,430	474,857	2,236,287	$86
100/200	16071	7600	9,607,000	3,474,250	935,110	4,409,360	$170

[Assuming 4 month lagoon scenario,775 lb-N/acre-year &]
[290 days/year available for vehicular application of TN collected]

Table 8 - Tillamook Energy Self-Sufficiency

%Collect/%Cow#'s 50/100	$/gal	Mg-TS	Herdsize	MW	kWh/d	Qeff	$/Mg	$/kWh	$kW-Sold	$Loan	YManure$	ACost$	TCC$	$NetCost	$Cost/Cow
10%-TS	1.10	114.92	16736	3.33	79850	1149	25.60	0.064	1,748,700	464,100	1,073,766	1,874,543	4,768,000	(125,843)	(8)
	2.00	114.92	16736	3.33	79850	1149	32.00	0.074	1,748,700	464,100	1,342,207	2,142,985	4,768,000	(394,285)	(24)
Self-Suff'nt	1.10	114.92	16736	3.12	74877	1149	25.60	0.070	1,639,798	480,408	1,073,813	1,915,402	4,935,545	(275,605)	(16)
13%-TS	1.10	114.92	16736	3.33	79850	1149	19.62	0.055	1,748,700	440,739	823,081	1,609,076	4,528,000	139,624	8
	2.00	114.92	16736	3.33	79850	1149	24.53	0.062	1,748,700	440,739	1,028,886	1,814,881	4,528,000	(66,181)	(4)
Self-Suff'nt	1.10	114.92	16736	3.17	76001	1149	19.63	0.059	1,664,413	453,377	823,396	1,641,002	4,657,834	23,412	1

Scenario Results

Some sense about the magnitude and range of possibilities for a county wide dairy waste treatment project should be apparent upon inspection of the figures and tables included with this report. A 'bottom line' comparison of cost per cow for several of the most likely and best case scenarios can be drawn from figures 16 and 17. A tabulation of estimated values calculated for digester scenarios figured are presented in tables 8 through 12. A cumulative summation of the various digester and secondary treatment scenarios is presented in tables 13 to 16. To aid with interpreting tables 8 thru 16 an explanation of the parameters presented and a brief discussion of notable values computed among the various scenarios concludes this report. The values referred to below are drawn from tables 8 through 12 and highlight high and/or low extremes for both All-county and Initial Start-up scenarios.

Scenario Assumptions: The first three columns in the table indicate the assumptions used to define the scenario.

Plant Site: Individual plant sites are identified by the area's name. "Three Plants" is an all-county summation or average of values in the scenario of having three separate treatment plants. Similarly "Two Plants" refers to the scenario of having just south county and central county sites. "Single Plant" refers to a central plant serving the entire county.

%-TS: The raw waste total solids concentration being hauled.

%Collection/%Cow#'s: Extent of manure collection, e.g. 100/100 indicates the assumption of 100% collection of 100% cow numbers.

Mg-TS: The metric tons of daily total solids assumed for the plant size.

Herdsize: The number of 1400 lb cow-units being served by the plant.

Tabulated Results: The middle three columns deal with digester output, and the right-hand columns present the economic factors of operation.

MW: The electrical power plant size in Megawatts. All-county: 5.15 MW for a single plant at 10%-TS is the high end possible for 50% collection of 200% cow#'s. Start-up: 0.48 MW for 100% collection of 15% of central Tillamook cow#'s.

kWh/d: The kilowatt hour per day output of the plant. All-county: The 5.15 MW plant generates 123,600 kWh/d. Start-up: A 0.48 MW plant generates 11,400 kWh/d.

Qeff: The volume of effluent, in cubic meters per day, that will have to be stored and disposed of. All-county: The maximum amount of effluent to be handled is 2540 m^3/day (671,000 gal/day) at 7%-TS. Influent at 10%-TS yields 1780 m^3/day (470,230 gal/day). Start-up: For 15% cow#'s, there would be 257 m^3/day (67,900 gal/day) at 7%-TS. Influent at 10%-TS yields 180 m^3/day (47,550 gal/day).

$/Mg: The assumed trucking cost in dollars per metric ton, including backhauling effluent. All-county: The cheapest hauling cost is $19/Mg for three plants and 13%-TS. $47/Mg is the high end value for a single plant and 7%-TS. Start-up: $37/Mg at 7%-TS, and $20/Mg at 13%-TS.

$/kWh: The cost of production of electricity. All-county: The best rate is $0.055/kWh for the individual Tillamook plant at 13%-TS. The worst rate is $0.111/kWh for the individual Nehalem plant at 7%-TS. The best all county rate is $0.059/kWh for two plants at 13%-TS. Start-up: With 15% cow#'s, at 7%-TS raw waste, the rate is $0.124/kWh. At 13%-TS, the rate is $0.86/kWh. Allowing for seasonal effects and 10%-TS, the effective annual rate is $0.11/kWh.

$kW-Sold: Annual value of electricity sold. All-county: The 5.15 MW plant generates $2,707,600 of revenue per year at a buy-back rate of $0.06/kWh. Start-up: The initial plant could sell $249,700 of revenue at 100% collection. Allowing for seasonal variation in manure supply, revenues would amount to $190,350 per year.

$Loan: The annual expense for debt repayment. All-County: The greatest expense is $997,000/year for three plants and 7%-TS and 9% interest. The lowest debt is $632,880/year for a single plant and 13%-TS. Start-up: Ranges between $102,200 and $128,290 per year.

YManure$: The yearly cost of trucking operations. All-county: The most costly is a single plant at 7%-TS, at $3,035,000/year. The best all county scenario is $1,250,000/year for three plants and 13%-TS. Start-up: Trucking costs range between $129,080 and $243,800 per year, depending on raw waste concentrations.

ACost$: The annual cost of operation. All-county: The highest annual cost is $4,509,400/year for a single plant and 7%-TS. The lowest cost is $2,645,400/year for two plants at 13%-TS. Start-up: Costs range from $356,200 to 516,200 per year for a 15% cow#'s scenario.

TCC$: Total Capital Costs. All-county: The most costly scenario is $10,209,000 for the construction of three plants at 7%-TS. The cheapest plant scenario is $6,502,000 for a single plant at 13%-TS. Start-up: An initial digester system is estimated to cost from $1,050,000 to $1,320,000.

$NetCost: The difference between cost of operation minus the value of electricity sold. All-county: The most expensive scenario is a single plant at 7%-TS, costing $1,801,600/year. A best case is for Two plants at 13%-TS, yielding a net return of $52,300 per year. Start-up: Net cost for a 15% sized digester range from $106,500 to $266,500 per year.

$Cost/Cow: The net cost of operation divided by the number of cows on participating dairies. All-county: The highest all county rate is $69/cow per year for the most expensive scenario. The best scenario earns $2/cow per year, for two plants at 13%-TS and 100%/100% collection and cow#'s. Start-up: An initial plant could cost between $49 and $106 per cow per year, depending on raw waste concentrations and trucking costs.

Table 9 - Slurry Concentration Scenarios

%Collect/%Cow#'s 100/100	%TS	Mg-TS	Herdsize	MW	kWh/d	Qeff	$/Mg	$/kWh	$kW-Sold	$Loan	YManure$	ACost$	TCC$	$NetCost	$Cost/Cow
Nehalem	7	14.00	2005	2.00	8564	140	29.93	0.111	187,600	87,797	152,942	347,414	902,000	(159,814)	(80)
	10	14.00	2005	0.36	8564	140	20.66	0.097	187,600	87,797	105,573	303,329	902,000	(115,729)	(58)
	13	14.00	2005	0.36	8564	140	15.84	0.090	187,600	87,797	80,942	280,468	902,000	(92,868)	(46)
Cloverdale	7	49.00	7255	1.42	34035	700	36.28	0.097	745,400	303,689	648,868	1,202,245	3,120,000	(456,845)	(63)
	10	49.00	7255	1.42	34025	490	25.04	0.070	745,100	222,316	447,841	873,410	2,284,000	(128,310)	(18)
	13	49.00	7255	1.42	34025	490	19.20	0.062	745,100	222,316	343,392	775,152	2,284,000	(30,052)	(4)
Tillamook	7	114.92	16736	3.33	79860	1642	37.08	0.088	1,748,900	602,220	1,555,283	2,572,498	6,187,000	(823,598)	(49)
	10	114.92	16736	3.33	79850	1149	25.60	0.064	1,748,700	464,100	1,073,766	1,874,543	4,768,000	(125,843)	(8)
	13	114.92	16736	3.33	79850	1149	19.63	0.055	1,748,700	440,739	823,360	1,609,356	4,528,000	139,344	8
Tillamook	7	128.92	18741	3.73	89584	1842	41.63	0.095	1,961,900	693,424	1,958,857	3,106,634	7,124,000	(1,144,734)	(61)
	10	128.92	18741	3.73	89570	1289	28.73	0.068	1,961,600	520,944	1,351,861	2,236,810	5,352,000	(275,210)	(15)
w/Nehalem	13	128.92	18741	3.73	89570	1289	22.03	0.057	1,961,600	474,223	1,036,599	1,879,235	4,872,000	82,365	4
Three Plants	7	177.92	25996	6.75	122459	2482	36.30	0.092	2,681,900	993,707	2,357,093	4,122,157	10,209,000	(1,440,256)	(55)
	10	177.92	25996	5.10	122439	1779	25.06	0.068	2,681,400	774,213	1,627,179	3,051,282	7,954,000	(369,882)	(14)
	13	177.92	25996	5.10	122439	1779	19.21	0.060	2,681,400	750,853	1,247,695	2,664,976	7,714,000	16,424	1
Two Plants	7	177.92	25996	5.15	123619	2542	40.16	0.095	2,707,300	997,114	2,607,725	4,308,879	10,244,000	(1,601,579)	(62)
	10	177.92	25996	5.15	123594	1779	27.71	0.069	2,706,700	743,260	1,799,702	3,110,220	7,636,000	(403,519)	(16)
	13	177.92	25996	5.15	123594	1779	21.25	0.059	2,706,700	696,539	1,379,991	2,654,387	7,156,000	52,313	2
Single Plant	7	177.92	25994	5.15	123643	2542	46.73	0.100	2,707,800	912,431	3,034,599	4,509,387	9,374,000	(1,801,587)	(69)
	10	177.92	25994	5.15	123634	1779	32.27	0.071	2,707,600	679,602	2,095,581	3,221,047	6,982,000	(513,447)	(20)
	13	177.92	25994	5.15	123634	1779	24.74	0.060	2,707,600	632,881	1,606,590	2,695,934	6,502,000	11,666	0

Table 10 - Tillamook Phased Expansion

100%Collection															
%Cow#'s	%TS	Mg-TS	Herdsize	MW	kWh/d	Qeff	$/Mg	$/kWh	$kW-Sold	$Loan	YManure$	ACost$	TCC$	$NetCost	$Cost/Cow
15%	7	18.02	2510	0.48	11401	257	37.08	0.124	249,700	128,289	243,819	516,242	1,318,000	(266,542)	(106)
25%	7	29.42	4184	0.83	19821	420	37.08	0.109	434,100	202,070	398,109	788,699	2,076,000	(354,599)	(85)
50%	7	57.92	8368	1.68	40236	827	37.08	0.097	881,200	360,534	783,833	1,422,550	3,704,000	(541,350)	(65)
100%	7	114.92	16736	3.33	79858	1642	37.08	0.088	1,748,900	602,220	1,555,283	2,572,498	6,187,000	(823,598)	(49)
15%	10	18.02	2510	0.48	11400	180	25.63	0.095	249,700	102,203	168,529	393,366	1,050,000	(143,666)	(57)
25%	10	29.42	4184	0.83	19826	294	25.63	0.083	434,200	163,525	275,176	598,111	1,680,000	(163,911)	(39)
50%	10	57.92	8368	1.68	40226	579	25.60	0.071	880,900	270,887	541,158	1,039,033	2,783,000	(158,133)	(19)
100%	10	114.92	16736	3.33	79850	1149	25.60	0.064	1,748,700	464,100	1,073,766	1,874,543	4,768,000	(125,843)	(8)
15%	13	18.02	2510	0.48	11400	180	19.63	0.086	249,700	102,203	129,077	356,189	1,050,000	(106,489)	(42)
25%	13	28.92	4184	0.81	19448	289	19.63	0.075	425,900	161,870	207,175	530,867	1,663,000	(104,967)	(25)
50%	13	57.92	8368	1.68	40226	579	19.63	0.063	880,900	270,887	414,958	920,150	2,783,000	(39,250)	(5)
100%	13	114.92	16736	3.33	79850	1149	19.63	0.055	1,748,700	440,739	823,360	1,609,356	4,528,000	139,344	8

Table 11 - Seasonal Variability Effect; Tillamook Expanssion Scenarios

10%-TS															
%Cow#'s	%Colle	Mg-TS	Herdsize	MW	kWh/d	Qeff	$/Mg	$/kWh	$kW-Sold	$Loan	YManure$	ACost$	TCC$	$NetCost	$Cost/Cow
15%	100%	18.02	2510	0.48	11400	180	25.63	0.095	249,700	102,203	168.529	393,400	1,050,000	(143,700)	(57)
	50%	9.47	2510	0.25	5983	95	25.63	0.146	131,000		88.545	319,300		(188,300)	(75)
Annual Totals/Avg's		13.74	2510	0.36	8692	137	25.63	0.11	190,350	102,203	128.537	356,350	1,050,000	(166,000)	(66)
50%	100%	29.42	8368	0.90	21620	294	25.60	0.095	473,500	250,057	274.854	747,700	2,569,000	(274,200)	(33)
50%	50%	57.92	8368	1.68	40228	579	25.60	0.071	881,000	270,887	541.158	1,039,000	2,783,000	(158,000)	(19)
Annual Totals/Avg's		43.67	8368	1.29	30924	437	25.60	0.08	677,250	260,472	408,006	893,350	2,569,000	(216,100)	(26)
100%	100%	114.92	16736	3.33	79850	1149	25.60	0.064	1,748,700	464,100	1,073.766	1,874,500	4,768,000	(125,800)	(8)
100%	50%	57.92	16736	1.81	43452	579	25.60	0.081	951,600	419,617	541.158	1,287,000	4,311,000	(335,400)	(20)
Annual Totals/Avg's		86.42	16736	2.57	61651	864	25.60	0.07	1,350,150	441,858	807,462	1,580,750	4,768,000	(230,600)	(14)

Table 12 - All County, Two Plant Scenarios

100/100	%TS	Mg-TS	Herdsize	MW	kWh/d	Qeff	$/Mg	$/kWh	$kW-Sold	$Loan	YManure$	ACost$	TCC$	$NetCost	$Cost/Cow
Cloverdale	13	25.00	7255	0.69	16503	250	19.20	0.079	361,400	149,217	175,200	475,722	1,533,000	(114,322)	(16)
	13	49.00	7255	1.42	34027	490	19.20	0.062	745,200	222,316	343,392	775,152	2,284,000	(29,952)	(4)
	13	49.00	14510	1.42	34027	490	19.20	0.062	745,200	222,316	343,392	775,152	2,284,000	(29,952)	(2)
	13	99.00	14510	2.87	68778	990	19.20	0.056	1,506,200	401,707	693,792	1,413,428	4,127,000	92,772	6
	10	25.00	7255	0.69	16503	250	25.04	0.082	361,400	125,856	228,490	496.552	1,293,000	(135,152)	(19)
	10	49.00	7255	1.42	34027	490	25.04	0.070	745,200	222,316	447,841	873.410	2,284,000	(128,210)	(18)
	10	49.00	14510	1.42	34027	490	25.04	0.070	745,200	222,316	447,841	873.410	2,284,000	(128,210)	(9)
	10	99.00	14510	2.87	68778	990	25.04	0.064	1,506,200	401,707	904,820	1,611,948	4,127,000	(105,748)	(7)
Tllmk	13	64.92	18741	1.88	45090	649	22.03	0.063	987,500	266,702	521,978	1,031,252	2,740,000	(43,752)	(2)
	13	128.92	18741	3.73	89569	1289	22.03	0.057	1,961,600	474,223	1.036.599	1,879,235	4,872,000	82,365	4
w/Nehalem	13	128.92	37481	3.73	89569	1289	22.03	0.057	1,961,600	474,223	1.036.599	1,879,235	4,872,000	82,365	2
	13	255.92	37481	7.41	177853	2559	22.03	0.054	3,895,000	845,950	2.057.800	3,482,780	8,691,000	412,220	11
	10	64.92	18741	1.88	45090	649	28.73	0.074	987,500	290,062	680,728	1,211,101	2,980,000	(223,601)	(12)
	10	128.92	18741	3.73	89569	1289	28.73	0.068	1,961,600	520,944	1.351.861	2,236,810	5,352,000	(275,210)	(15)
	10	128.92	37481	3.73	89569	1289	28.73	0.068	1,961,600	520,944	1.351.861	2,236,810	5,352,000	(275,210)	(7)
	10	255.92	37481	7.41	177853	2559	28.73	0.065	3,895,000	939,393	2.683.640	4,193,489	9,651,000	(298,489)	(8)
[Two	13	89.92	25996	2.57	61593	899	21.24	0.067	1,348,900	415,918	697,178	1,506,974	4,273,000	(158,074)	(6)
	13	177.92	25996	5.15	123596	1779	21.25	0.059	2,706,800	696,539	1.379.991	2,654,387	7,156,000	52,413	2
Plants]	13	177.92	51991	5.15	123596	1779	21.25	0.059	2,706,800	696,539	1.379.991	2,654,387	7,156,000	52,413	1
	13	354.92	51991	10.28	246631	3549	21.24	0.054	5,401,200	1,247,657	2.751.592	4,896,208	12,818,000	504,992	10
	10	89.92	25996	2.57	61593	899	27.70	0.076	1,348,900	415,918	909,218	1,707,653	4,273,000	(358,753)	(14)
	10	177.92	25996	5.15	123596	1779	27.71	0.069	2,706,800	743,260	1.799.702	3,110,220	7,636,000	(403,419)	(16)
	10	177.92	51991	5.15	123596	1779	27.71	0.069	2,706,800	743,260	1.799.702	3,110,220	7,636,000	(403,419)	(8)
	10	354.92	51991	10.28	246631	3549	27.70	0.064	5,401,200	1,341,100	3.588.460	5,805,437	13,778,000	(404,237)	(8)

Cumulative Totals: To attain some sense of the range of ultimate costs that could be expected for the waste treatment system overall, a comparison of the different collection scenarios for a two plant system trucking 10% or 13%-TS raw waste is summarized in tables 13 & 14. Tables 15 and 16 provide similar summations for start-up, phased expansion scenarios. The cumulative sums progress from digester costs alone, to digester costs plus solids recovery with commercial value, to digester and solids recovery and lagoon storage, and finally including the forest land ultimate disposal alternative.

All-county: The best case cost per cow for a digester system alone earns \$1/cow per year at 13%-TS and 50% collection of 200% cow#'s. In adding in an expected return of \$100/ton for 30% recovery of the digester effluent solids, this scenario could earn as much as \$10/cow per year. Including a lagoon storage system for this scenario would decrease annual earnings to \$8/cow per year. Finally, to dispose of the digester/lagoon effluent to forest lands would cost \$35 per cow per year. The most costly scenario analyzed projects cumulative costs through lagoon storage at \$7/cow per year and at \$87/cow per year for forest land disposal. Start-up & Phased Expansion: An initial Tillamook plant serving 15% of local area cows could cost \$57/cow per year for the digester alone. Upon realizing a return for marketed solids, the cost could be reduced to \$26/ cow per year. Finally, including lagoon storage, the cumulative total costs for a start-up system is estimated at \$36/cow per year. A fully developed Tillamook plant, serving 100% of the herd size within a 10.5 mile range of the Port of Tillamook site could turn a profit of \$10/cow per year for a digester alone. Upon marketing of solids, earnings of $70 to $80 per cow, including lagoon storage, may be possible.

Figure 16-Cumulative Economic Scenarios
Two Plant, All County Assumptions

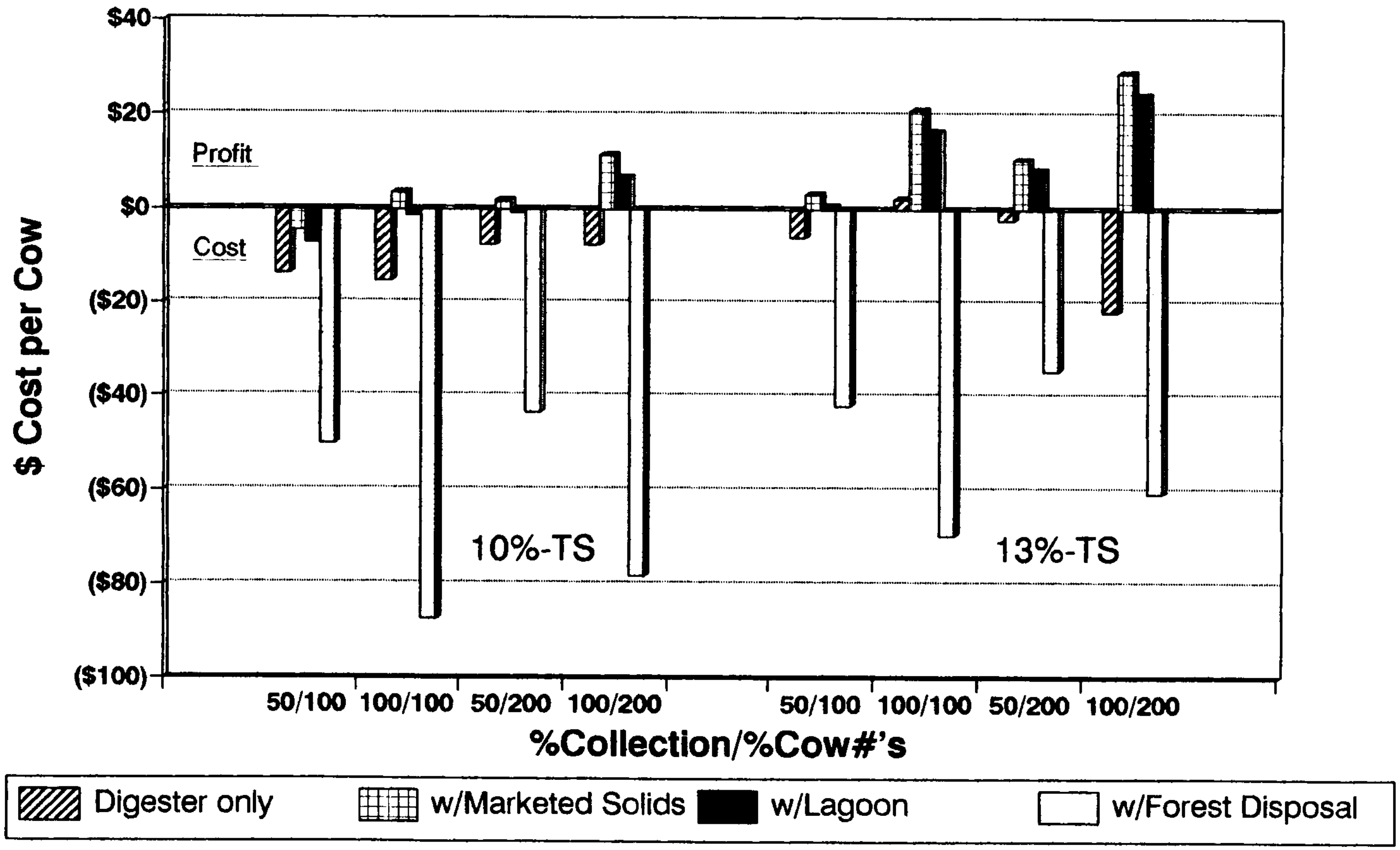


Figure 17-Cumulative Economic Scenarios
Central Tillamook Start-Up/Expansion

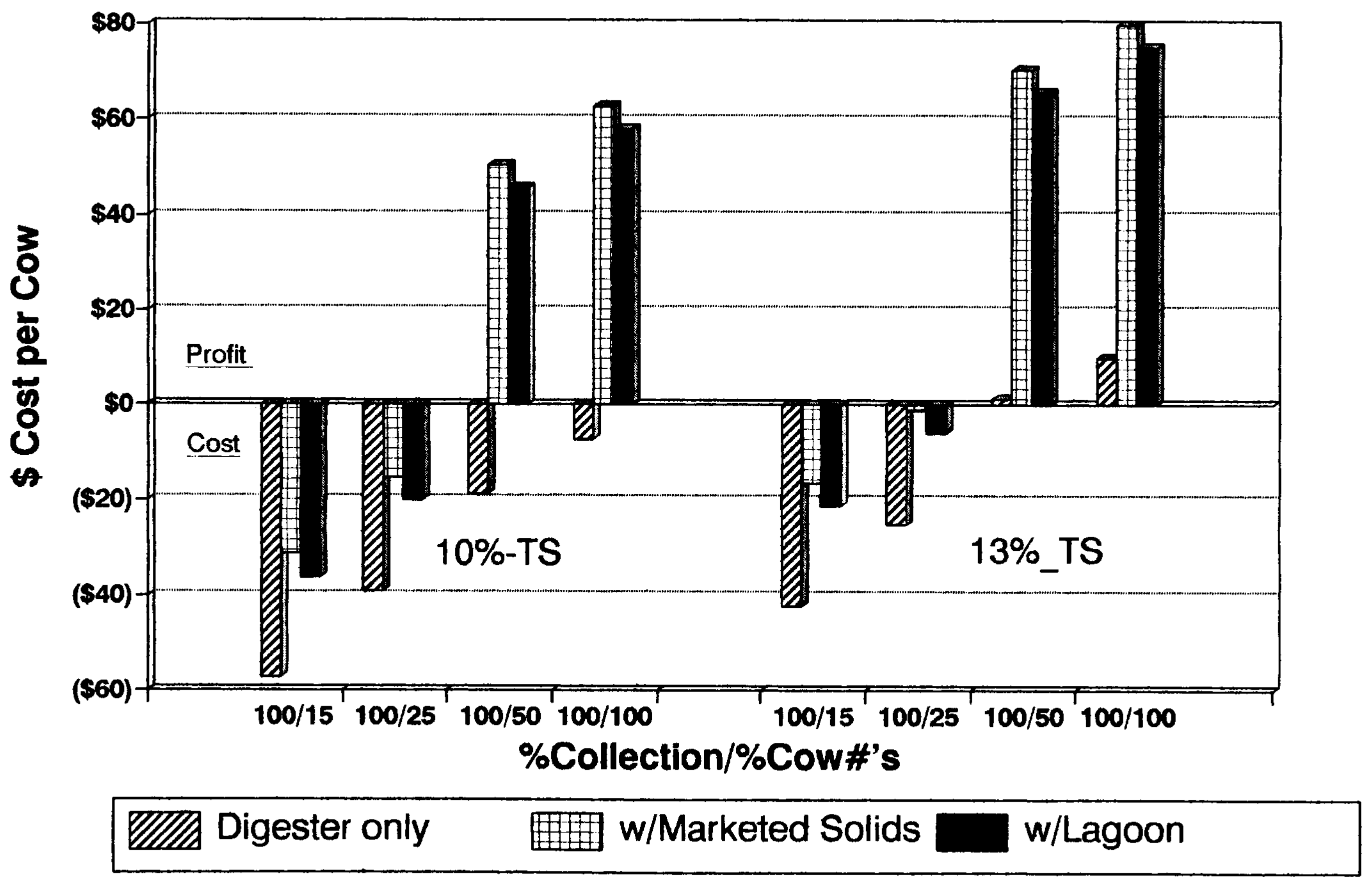


Table 13 - Cumulative Economic Scenarios

System Costs

%Collection/Cow#'s 10% TS Raw Waste	Cost per Cow	Annual Net Cost	Capital Cost	Cumulative Totals		
50/100				Cost per Cow	Annual Cost	Capital Cost
Digester	14	358,753	4,273,000			
Solids Removal	(9)	(235,303)	514,068	5	123,449	4,787,068
Lagoon Storage	2	61,705	465,500	7	185,154	5,252,568
Forest Application	43	1,119,739	2,439,260			
				50	1,304,893	7,691,828
100/100						
Digester	16	403,419	7,636,000			
Solids Removal	(19)	(490,249)	894,121	(3)	(86,829)	8,530,121
Lagoon Storage	5	121,633	917,600	1	34,804	9,447,721
Forest Application	86	2,236,287	4,878,520			
Totals				87	2,271,091	14,326,241
50/200						
Digester	8	403,419	7,636,000			
Solids Removal	(9)	(490,249)	894,121	(2)	(86,829)	8,530,121
Lagoon Storage	2	121,633	917,600	1	34,804	9,447,721
Forest Application	43	2,236,287	4,878,520			
Totals				44	2,271,091	14,326,241
100/200						
Digester	8	404,237	13,778,000			
Solids Removal	(19)	(985,895)	1,770,123	(11)	(581,657)	15,548,123
Lagoon Storage	5	242,700	1,831,000	(7)	(338,958)	17,379,123
Forest Application	85	4,409,360	9,607,000			
Totals				78	4,070,403	26,986,123

[(positive value), Two plants, all county scenarios]

Table 14 - Cumulative Economic Scenarios

System Costs

%Collection/Cow#'s 13% TS Raw Waste	Cost per Cow	Annual Cost	Capital Cost	Cumulative Totals		
50/100				Cost per Cow	Annual Cost	Capital Cost
Digester	6	158,074	4,273,000			
Solids Removal	(9)	(235,303)	514,068	(3)	(77,230)	4,787,068
Lagoon Storage	2	61,705	465,500	(1)	(15,525)	5,252,568
Forest Application	43	1,119,739	2,439,260			
Totals				42	1,104,214	7,691,828
100/100						
Digester	(2)	(52,413)	7,156,000			
Solids Removal	(19)	(490,249)	894,121	(21)	(542,661)	8,050,121
Lagoon Storage	5	121,633	917,600	(16)	(421,029)	8,967,721
Forest Application	86	2,236,287	4,878,520			
Totals				70	1,815,259	13,846,241
50/200						
Digester	(1)	(52,413)	7,156,000			
Solids Removal	(9)	(490,249)	894,121	(10)	(542,661)	8,050,121
Lagoon Storage	2	121,633	917,600	(8)	(421,029)	8,967,721
Forest Application	43	2,236,287	4,878,520			
Totals				35	1,815,259	13,846,241
100/200						
Digester	(10)	(504,992)	12,818,000			
Solids Removal	(19)	(985,895)	1,770,123	(29)	(1,490,887)	14,588,123
Lagoon Storage	5	242,700	1,831,000	(24)	(1,248,187)	16,419,123
Forest Application	85	4,409,360	9,607,000			
Totals				61	3,161,173	26,026,123

[(positive value), Two plant, all county scenarios]

Table 15 - Cumulative Economic Scenarios

System Costs - Tillamook Start-up

%Collection/Cow#'s 10% TS Raw Waste	Cost per Cow	Annual Cost	Capital Cost	Cumulative Totals		
100/15				Cost per Cow	Annual Cost	Capital Cost
Digester	57	143,666	1,050,000			
Solids Removal	(26)	(65,017)	250,532	31	78,649	1,300,532
Lagoon Storage	5	12,461	94,000	36	91,110	1,394,532
Forest Application	NA	NA	NA			
Totals				36	91,110	1,394,532
100/25						
Digester	39	163,911	1,680,000			
Solids Removal	(24)	(99,584)	288,979	15	64,327	1,968,979
Lagoon Storage	5	20,175	152,200	20	84,502	2,121,179
Forest Application	NA	NA	NA			
Totals				20	84,502	2,121,179
100/50						
Digester	19	158,133	2,783,000			
Solids Removal	(69)	(580,217)	390,783	(50)	(422,084)	3,173,783
Lagoon Storage	5	39,753	299,900	(46)	(382,331)	3,473,683
Forest Application	NA	NA	NA			
Totals				(46)	(382,331)	3,473,683
100/100						
Digester	8	125,843	4,768,000			
Solids Removal	(70)	(1,172,753)	616,374	(63)	(1,046,910)	5,384,374
Lagoon Storage	5	78,911	595,300	(58)	(967,999)	5,979,674
Forest Application	NA	NA	NA			
Totals				(58)	(967,999)	5,979,674

[(positive value)]

Table 16 - Cumulative Economic Scenarios

System Costs - Tillamook Start-up

%Collection/Cow#'s 13% TS Raw Waste	Cost per Cow	Annual Cost	Capital Cost	Cumulative Totals		
100/15				Cost per Cow	Annual Cost	Capital Cost
Digester	42	106,489	1,050,000			
Solids Removal	(26)	(65,017)	250,532	17	41,472	1,300,532
Lagoon Storage	5	12,461	94,000	21	53,933	1,394,532
Forest Application	NA	NA	NA			
Totals				21	53,933	1,394,532
100/25						
Digester	25	104,967	1,663,000			
Solids Removal	(24)	(99,584)	288,979	1	5,383	1,951,979
Lagoon Storage	5	20,175	152,200	6	25,558	2,104,179
Forest Application	NA	NA	NA			
Totals				6	25,558	2,104,179
100/50						
Digester	(1)	39,250	2,783,000			
Solids Removal	(69)	(580,217)	390,783	(70)	(540,966)	3,173,783
Lagoon Storage	5	39,753	299,900	(66)	(501,213)	3,473,683
Forest Application	NA	NA	NA			
Totals				(66)	(501,213)	3,473,683
100/100						
Digester	(10)	(139,344)	4,528,000			
Solids Removal	(70)	(1,172,753)	616,374	(80)	(1,312,098)	5,144,374
Lagoon Storage	5	78,911	595,300	(75)	(1,233,186)	5,739,674
Forest Application	NA	NA	NA			
Totals				(75)	(1,233,186)	5,739,674

[(positive value)]

CONCLUSIONS & RECOMMENDATIONS

The task of remedying the manure management problems of Tillamook County dairies with a centralized, county-wide waste treatment system will necessitate undertaking a rather complex and comprehensive activity, requiring participation and cooperation among a large majority of area dairymen, county agencies, and residents. There is an economy of scale involved which would allow area dairies to benefit from sharing in a common, management intensive waste treatment system, as opposed to multiple, individual dairy systems. Installation of one or two methane production plants, including lagoon storage and solids recovery facilities central to Tillamook and Cloverdale, serving all the dairies in the county is technically feasible for treating and reducing pathogen and nitrogen levels in county watersheds. Achieving this accountability of potential animal waste pollutants could then, in turn, permit area dairies to expand their milking herds to meet the Tillamook Creamery's production capacity while realizing increased income per dairy, which in turn would boost annual revenues per capita county wide. The scale of the project should not be underestimated. In order to treat all of the manure generated by the current cow population will require construction and management of waste facilities comparable in size to a city of 250,000 population. The proposed project will be essentially supported by the 191 dairies that could benefit by it, and these dairies will be committed to a 30 year investment of capital for the facilities. The social, economic and political aspects involved in bringing so many individuals into agreement for such a long term commitment will need to be resolved. As the cumulative cost scenarios from tables 13 through 16 indicate, the economic feasibility of a comprehensive waste treatment system looks very promising. There are hidden costs that have not been accounted for regarding per farm capital improvements that will need to be made among participating dairies, especially concerning return of the effluent for farm land application. The alternative of forest land application could be very attractive to dairymen who would just as well see their manure leave their property for good and not have to trouble with it upon return. The prospect of an economic return from forest lands benefiting from sludge fertilization has not been evaluated for this study. The commercial potential for solids recovery and resale as slow release fertilizer needs to be more fully analyzed. This facet of the overall treatment system appears to offer the possibility that a net annual profit per cow could be realized, if the market and price is right. On the other hand, the chance that the solids recovery operation could yield such a massive amount of solids on a daily basis that potential markets could be flooded with a surplus of supply, hence diminishing wholesale prices, needs to be considered. The firm Unisyn, Inc. of Seattle may be able to provide a solids marketing analysis to the M.E.A.D Policy Committee in the near future. Given that there are so many variables involved regarding both the technical aspects and economic prospects for the M.E.A.D. project, it is impossible in this study to give a single definitive answer as to what it might all cost and how it can be precisely accomplished. Estimates made regarding the performance and cost of an anaerobic digester can be accepted with a fair degree of confidence, given the detailed level of variables and calculations required for the computer program on digester design. Economic projections for the additional system components of lagoon storage, solids removal, and forest land disposal were made with less sophisticated model algorithms, and should be considered accordingly. More accurate estimates can be attained only from engineering/construction firms retained to begin making site specific design proposals. The best this report can offer is a picture of the technical alternatives and an indication of the range in dollars it may cost. Assuming that the economic feasibility of the M.E.A.D. project as presented in this report appears encouraging to pursue, this paper concludes with the following recommendations:

- Board of Directors - before the task of any construction and implementation of a waste treatment system can begin, interested parties with the M.E.A.D Project must decide upon what legal entity or organization is going to be responsible - funding, permits, retention of engineering firms, etc., obviously must be undertaken by an agency other than 'by committee'.
- Pilot Plant - given the magnitude of the proposed project and the many variables involved affecting production rates and design costs, the construction and study of a pilot scale methane digester is recommended. A pilot scale plant, treating a representative mix of county dairy manures, would allow for verification of the influent waste characteristics, for methane yield, for trucking, and for effluent waste characteristics. A pilot plant would provide an opportunity to evaluate pathogen reductions occurring in anaerobic digestion. A volume of material would be generated with which to assess nitrogen reduction techniques that could not be readily evaluated by laboratory bench-scale experiments, such as the rate of ammonia volatilization in handling and 'mini-lagoon' experiments. The digester sludge solids could also be analyzed for its fertilizer value and assessed for its market value, providing a better prediction for the worth of a solids recovery operation as part of the system. Furthermore, a pilot plant could introduce all those who may be participating in the project to the technology and convince them of its practicality, before committing themselves to a 30 year contract. The pilot plant could be situated and designed as the start-up, first phase of the project, servicing 2000 to 2500 cow-units from some of the more troublesome central Tillamook dairies.
- Lagoon Study - in connection with the pilot plant a study verifying nitrogen transformations occurring in area dairy lagoons under the environmental conditions of coastal Oregon could better predict lagoon design requirements and costs for the full scale project.

- TCCA Dairy Survey - a questionnaire sent to all active dairy members of the TCCA could yield up to date information concerning: the county cow population, current manure management systems, acreage available for application, estimated capital improvement costs to bring each operation into conformity to facilitate a centralized system, opinions on scenario 'likelihoods' (e.g. collection efficiency, seasonal variations, expanded herd size), and interest levels to participate.

- Forest Land Application - an in depth study should be undertaken assessing the possibility of disposing of dairy sludge wastes upon Tillamook regional forest lands. The prospect of realizing an accelerated harvestable return on carefully chosen forest lands, not to mention the convenience to valley dairymen of seeing their manure leave their property and not come back, warrants careful evaluation.

- Methane Powered Vehicles - operation of a pilot plant would also generate enough gas to enable a technical evaluation of operating large trucks on methane gas. Determining conversion efficiencies and problems that would accurately determine a 'break even' price compared to petroleum fuels for operation of the system truck fleet could aid the economic security of the whole project.

- Phase-in Full Scale Implementation - if the recommendations above are carried through and the feasibility of the project is affirmed, the scenario estimates by this analysis suggest phasing in construction of the necessary facilities. The initial installation could be the pilot plant designed to accept the manure collectible by 15% of the current cow population (at whatever collection efficiency determined as likely) within the central Tillamook area. This plant could serve the entire county, adding digester tanks as expansion of the county herd size and upgrading of individual dairy manure collection methods generate enough waste to exceed the plant's capacity. At that point, actual trucking costs and operational costs will be known by which to determine if a single centralized Tillamook plant should be expanded, or if a second Cloverdale facility should be constructed.

A Comparison of Tillamook Dairy Manures for Ultimate Methane Yield

INTRODUCTION

With the decision to proceed in developing a Tillamook methane generation facility (a decision based in part by the conclusions from the previous feasibility study), an essential factor to the digester design is the potential ultimate methane yield of the manure to be processed. Determination of the ultimate methane yield provides the coefficient, Bo (ml-CH_4/g-VS). This term is needed for the key engineering formula of digester design, which is a function predicting the rate of methane production:

$$y_v = (Bo\ So\ /\ HRT)\ (1 - (K\ /\ (HRT\ u_m - 1 + K))$$

where; y_v = volumetric production rate (liter-CH_4/liter fermenter-day); So = influent volatile solids concentration (g/liter); HRT = hydraulic retention time (day); K = kinetic parameter (dimensionless); u_m = specific growth rate (1/day).

For the design of a digester that will utilize influent from multiple sources, a better estimate of methane production will be obtained by the cumulative yield based on the particular Bo and volume of the different substrates to be used, rather than assuming an average Bo for all manure sources. The literature indicates that significant variability can be expected in the value of Bo for dairy manures. The variability of Bo as reported in the literature for dairy manure can range from 170 to 400 ml-CH_4/g-VS (Chen, *et.al*, 1978., Loehr, 1984). This variation can be attributed to a number of conditions affecting the quality of manure and its degradation under anaerobic conditions. These factors include the quality of the animal feed and the metabolic efficiency of the breed of animal and the efficiency, on the whole, of a particular dairy herd. Perhaps more significantly an effect on potential methane yield is due to the method of waste management and storage utilized by a dairy. Whether the manure is fresh or has been stored in liquid holding tanks, or in dry stack containing bedding, are all factors that can affect Bo.

The purpose of this study is to determine the potential ultimate methane yield for manures taken from several Tillamook County dairies, and show the correlation, if any, between the range of Bo's and the sample's origin. In order to assess the potential methane yield from biomass a common method is to ferment the substrate of interest under batch conditions with an appropriate inoculum until no more methane is produced.

METHODS

Experimental Design

Seventeen manure samples were taken from thirteen dairies assumed representative of the various management methods utilized among area operators. Dairies were selected by their ranking among the top quarter, middle half, and bottom quarter of average milk production. Manure samples were categorized by their source; from either stack or liquid storage systems, or fresh. The two-way distribution of the samples are indicated in Table 17 (replicated n=3).

Procedure

Serum bottles served as digester vessels. Each bottle had an effective volume of 119 ml when sealed with a 1cm thick black butyl rubber stopper (Bellco Glass, Vineland, N.J.). The fermenters were filled to a working volume of 50 ml, comprised of 25 ml of inoculum and 25 ml of substrate solution. Each digester was purged with O_2-free nitrogen prior to sealing and after the substrate-inoculum mix was added. The digesters were incubated at 35^{o} C$\pm$2 ^{o}. Volumetric gas production and biogas quality were measured regularly during the fermentation period.

Substrate and Inoculum

The manure samples were kept in polyethylene 1-liter bottles and frozen from the day of collection until the day of preparation (2 to 3 weeks), at which time they were thawed by partial immersion of the bottles in a warm water bath. It was desired to use the samples as near to a fresh and 'as-is' state as possible. However the relatively high solids content of 'dry-stack' samples due to straw bedding required preparing such samples differently from the liquid storage and fresh samples.

The liquid storage and fresh manure samples were prepared by running approximately 300 ml of raw material through an ordinary kitchen blender in order to obtain as homogeneous a mixture as possible. The blended material was then transferred to a 500 ml Nalgene beaker. The samples were kept mixed manually and the requisite substrate amount per digester was measured volumetrically by spooning 25 ml of material from the 500 ml beaker into a 50 ml Nalgene beaker. The 25 ml of substrate was then funnelled (Nalgene) into the serum bottles using a glass stirring rod as a prod and scraper. This method left negligible traces of residue on the surface of the beaker and funnel.

The manure samples with a high straw content did not permit blending or grinding in the raw condition that would produce an acceptably homogenized sample. Therefore these samples were prepared by dehydrating the samples before grinding. This was done by taking roughly half the raw material from the liter storage containers and dehydrating it at 102^{O} C for 15 hours. The material was then run through a grinder (1-mm screen, Thomas-Wiley laboratory mill) which produced a thoroughly mixed sample of straw and manure. The milled solids and tap water were then added to the fermenters to create a substrate mix containing 1.25 or 2.5 gm of total solids per 25 mL.

The inoculum was obtained from a three liter working volume fermenter acclimated to mesophilic conditions (35^{O} C) and periodically fed dairy manure during the previous year. The inoculum had not been fed for four weeks prior to starting the experiment and was considered to be in a 'starved' condition. The inoculum mixture was filtered through a No. 18 sieve (1-mm square mesh) to remove most of the old suspended solids and ensure that subsequent digestion would be attributable to the newly added manure substrate. Inoculum (25 ml) was pipetted into each digester after the 25 ml of substrate were added. A control sample of 50 ml of inoculum (in triplicate) was also run.

Analytical Methods

The total solids (TS) and volatile solids (VS) were determined using standard methods for wastewater analysis (American Public Health Association, 1989). Kjeldahl nitrogen values were determined using methods as modified for use with a Labconco rapid kjeldahl system.

Extractable phosphorous and potassium content were obtained through tests run by the Oregon State University Soil Testing Lab.

Volumetric gas production was measured by inserting the needle of a glass syringe into the serum bottle and allowing the displacement of the water-lubricated plunger in a horizontal position to equilibriate the bottle's gas volume to atmospheric pressure.

Biogas was analyzed to determine the concentration of methane and carbon dioxide using a Hewlett Packard 5890 Series II gas chromatograph. The instrument was set for use with a thermal conductivity detector and a $^1/_8$-inch stainless steel, Chromosorb 102 packed column (HP Analytic). Helium was used as the carrier gas. The injector, column, and detector temperatures were 100^o, 70^o, and 130^o C, respectively. Certified gas standard gases were used for calibration of the instrument to methane and carbon dioxide. An HP 3396A Integrator (calibrated according to a multi-level, point-to-point, norm method) interpreted detector signals directly to per cent gas concentrations.

Net methane production was obtained by subtracting half the replicate inoculum-control's average methane production from a sample's apparent total methane production. Methane yield (B, ml-CH_4/g-VS) was calculated by dividing the sample's net production by the average amount of VS in the particular prepared substrate. The average Bo and confidence interval within sample replicates and comparisons of significant difference between sample groups was calculated by an analysis of variance statistical package (Statgraphics, ver.4.0).

RESULTS AND DISCUSSION

Results

Table 18 presents the basic results of this study for the average methane yield and the methane concentration of the samples after 90 days, as well as the total solids and volatile solids composition of the raw waste. Table 19 shows results on the NPK of selected samples. An initial estimate of the fertilizer value of the digester effluent can be drawn from these values for nitrogen and potassium. The average nitrogen content of the six samples tested is 3.12% kjeldahl-N/dry-wt. The average soluble potassium fraction is 2.13% K/dry-wt. The soluble fraction of P and K is generally 85% of the total amount present, so the total average potassium content of the samples is estimated to be 2.51% K/dry-wt. Typical values found in the literature indicate expected values of 3.80% and 2.66% for dairy manure N and K values (Moore, J., *et. al.*, Midwest Plan Service (1987)). An expected value for phosphorus is 0.72%, which is considerably greater than the 0.15% P/dry-wt. given for the sample test results. No satisfactory explanation for this discrepancy has been determined. Table 20 presents, again, the average Bo and a 90% confidence interval for Bo given the statistical variance between replicates and overall between samples. The average Bo for all samples is 256 ml-CH_4/g-VS (250 - 263; 90% CI) with a high potential yield of 326 ml-CH_4/g-VS and a low yield of 164 ml-CH_4/g-VS.

Table 17 - Experimental Design
Source vs. Bo vs. Herd Milk Production

Samples (1-17)			
	Herd Milk Production		
Source	Bottom 1/4	Middle 1/2	Top 1/4
Fresh	7, 14	9	3, 4
Liquid store	1	6, 8, 17	2, 5
Dry-Stack	11, 15	10, 13	12, 16

Table 18 - Tillamook Waste Characteristics
& Biomethane Potential

Raw Waste Solids				BMP	Day-90
Sample	%TS	%VS	%VS/T	%CH4	Bo (ml/gm-
1,lb	5.5%	4.4%	80%	59%	323
2,lt	9.8%	7.6%	77%	58%	318
3,ft	14.4%	11.8%	82%	58%	306
4,ft	15.5%	10.6%	68%	55%	304
5,lt	10.2%	7.2%	70%	59%	300
6,lm	11.0%	8.3%	76%	59%	283
7,fb	16.3%	12.8%	78%	55%	267
8,lm	10.1%	7.9%	78%	55%	250
9,fm	17.9%	13.1%	73%	53%	249
10,sm	22.6%	12.6%	56%	56%	241
11,sb	17.6%	14.4%	82%	55%	228
12,st	17.6%	14.5%	82%	52%	228
13,sm	20.2%	15.8%	78%	52%	214
14,fb	14.4%	11.7%	81%	56%	213
15,sb	19.3%	16.5%	85%	53%	202
16,st	20.7%	15.9%	77%	54%	200
17,lm	7.3%	6.0%	83%	56%	162

*Protocol; l :liquid, f :fresh, s :stack
t :top quarter, m :middle half, b :bottom quarter

Discussion

An analysis of variance between dairy-source groups (Table 21) indicates a statistically significant difference, albeit slight ($p = 0.03$), between samples taken from the top-quarter milk producers (Bo_{tq} = 280 ml-CH_4/g-VS) and middle-half dairies (Bo_{mh} = 236 ml-CH_4/g-VS).

An analysis between manure-storage groups (Table 22) shows that the fresh and liquid storage samples potential methane yield are significantly different from the stack samples. The liquid storage samples have the highest average Bo, at 277 ml-CH_4/g-VS; fresh samples average 275 ml-CH_4/g-VS; and stack storage samples average 221 ml-CH_4/g-VS. It is difficult to assess to what extent the lower average Bo for stack samples was effected by drying the sample before fermentation. Although the volatile solids content used in calculating Bo was determined by the same procedure for all samples, there is obviously some loss of 'aromatic' volatile solids in the process of dehydration. Therefore, it is probable that the anaerobic bacteria fed the dehydrated stack samples were at a disadvantage, lacking some of the readily available nutrients present in the fresh and liquid samples. However it is expected that the stack samples would have a lower methane yield, due in part to a larger fraction of undigested (by cow) bedding material that is higher in lignin content, as well as simply being stored longer, generally, than the other two groups.

Finally, the average value of Bo for the fresh and liquid storage samples is effectively 276 ml-CH_4/g-VS, which corresponds very well with the assumption made in the feasibility study for the Bo of dairy manure as 280 ml-CH_4/kg-VS. The assumption of the study was that a digester would serve dairies using liquid storage systems.

Table 19-Composition of Selected Samples

Sample	%N/dry-wt*	%P+	%K+
3,ft	3.61	0.16	2.50
6,lm	3.85	0.13	2.93
8,lm	3.63	0.12	2.53
11,sb	3.28	0.19	1.95
14,fb	2.31	0.15	0.90
16,st	2.03	0.16	1.99

*Kjeldahl-N, (test on raw sample)

+Extractable P K,(all samples dehydrated & milled)

Table 20 - Multiple range analysis for Bo by Sample

Method: 90 Percent Tukey HSD Intervals				Statistically Similar
Sample	Bo (ave)	90% CI		(grouped by column)
1,lb	326	298	353	*
2,lt	322	294	350	*
3,ft	310	283	338	*
4,ft	310	283	338	* *
5,lt	307	279	334	* *
6,lm	287	259	314	* * *
7,fb	272	245	300	* * * *
8,lm	254	227	282	* * * *
9,fm	252	224	279	* * * *
10,sm	243	215	270	* * *
11,sb	231	203	258	* *
12,st	230	202	257	* *
13,sm	217	189	244	* * *
14,fb	216	182	250	* * *
15,sb	204	176	231	* *
16,st	202	175	230	* *
17,lm	164	137	192	*
Pooled average	256	250	263	

Table 21 - Multiple range analysis for Bo by Dairy Production

Method: 90 Percent Tukey HSD Intervals				Statistically Similar
Sample	Bo (ave)	90% CI		(grouped by columnn)
top 1/4	280	264	297	*
bottom 1/4	252	233	271	* *
middle 1/2	236	219	253	*
Pooled average	256	246	266	

Table 22 - Multiple range analysis for Bo by Manure Source

Method: 90 Percent Tukey HSD Intervals				Statistically Similar
Sample	Bo (ave)	90% CI		(grouped by columnn)
liquid	277	262	292	*
fresh	275	262	293	*
stack	221	206	236	*
Pooled average	256	247	266	

BIBLIOGRAPHY

Dept. of Community Development, ,1990, Annual Report, Tillamook County.

Hashimoto, Chen, Robinson, 1986, "Animal-waste Anaerobic Digestion System Design"; , Roman L. Hruska U.S. Meat Animal Research Center, Clay Center, NE. Modified for Tillamook scenarios 1990; Edgar,T., Dept. of Bioresource Engineering, OSU, Corvallis, OR.

Hashimoto, Chen,Varel, 1981, "Theoretical Aspects of Methane Production: State-Of-The-Art

Hashimoto, A.G., Chen,Y.R., 1981, "Economic Optimization of Anaerobic Fermenter Designs for Beef Production Units"; Livestock Waste: A Renewable Resource.

Hashimoto, A.G., 1982, "Performance of a Pilot-Scale, Thermophilic, Anaerobic Fermenter Treating Cattle Waste".

Metcalf & Eddy, 1979, Wastewater Engineering: Treatment, Disposal, Reuse; ,Section 11-7, "Stabilization: Anaerobic Sludge-Digestion Process".

Midwest Plan Service, 1987; Structures and Environment Handbook,, "Manure production and characteristics", table 701-1.

Moore, J.A., Gamroth M.J., 1989;"Calculating the fertilizer value of manure from livestock operations", OSU Extension publication, EC 1094.

Olsen, J.E., Larson, H.E., 1986, Biological Wastes,."Bacteria Decimation Time in Anaerobic Digestions of Animal Slurries"

Olsen, J.E., 1987, Biological Wastes "Studies on Reduction of Pathogens and Indicator Bacteria in Liquid Pig Manure Treated by Sedimentation and Anaerobic Filter Digestion for Methane Generation"

Sherwood, R.C., 1985, "Technology and Costs of Wastewater Application to Forests Systems", chapters 33,34. The Forest Alternative - Wastewater Treatment and Resource Recovery; , , University of Washington Press.

Sibidie, A.,1990, "Anaerobic Fermentation of Tillamook Dairy Manure"; Dept. of Bioresource Engineering, OSU.

TBRCWP, 1984, "Tillamook Bay Rural Clean Water Project, Annual Report.

U.S. Environmental Protection Agency, 1985, Handbook, Estimating Sludge Management Costs, Center for Environmental Research, Cincinnati, Ohio.

Urie, Dean H., 1985, "The Status of Wastewater Irrigation of Forests, 1985" Chpt. 3; The Forest Alternative - Wastewater Treatment and Resource Recovery; Charles H.L., et. al., Crites, R.W.,